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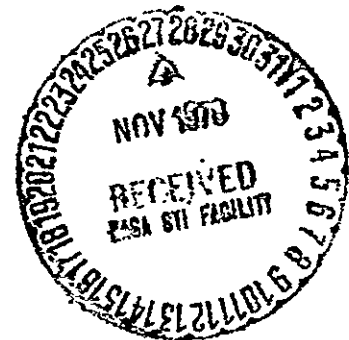
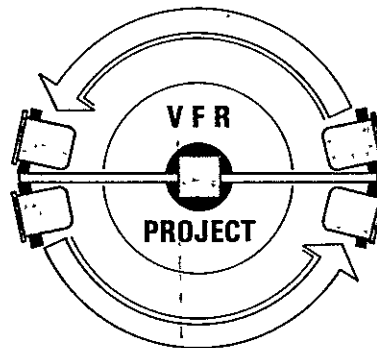
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VESTIBULAR FUNCTION RESEARCH (VFR)
EXPERIMENT

Phase B: Design Definition Study

FINAL REPORT



Prepared Under Contract NAS 2-9781

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Ames Research Center

BIOTECHNOLOGY, RESEARCH & DEVELOPMENT DIVISION

LOCKHEED MISSILES & SPACE COMPANY, INC.

A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

Sunnyvale, California 94088

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TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION AND SUMMARY	1
EXPERIMENT REQUIREMENTS	6
Specimen Canisters	6
Centrifuge/Canister Stimulus	6
Life Support	7
Control and Data Management	8
Electrical Power	10
MISSION MODE TRADEOFF	11
Spacelab Systems	11
Spacelab Configuration	11
Spacelab Interfaces	14
Spacelab Environments	24
Spacelab Mounted Experiment	24
Experiment Mounting	24
Spacelab Module Experiment Design	27
Pallet Mounted Experiment	27
VFR Mission Operations	30
Mission Mode Comparison	35
Spacelab Module Mounted Experiment	35
Pallet Mounted Experiment	39
Recommended Mission Mode	39
CONCEPTUAL DESIGN	40
Mission Trade Studies	40
Mission Options	40
Comparison of Specimen Loading and Unloading Options	43
Transport Equipment Options	43
Life Support System Trade Studies	48
Urea Control	48
Oxygen Supply	51
Oxygen Transfer to Water	51
Carbon Dioxide Removal	52
Solids Removal	52
Frog Washing	53
Bacteria Growth Control	54
Thermal Control	55

	<u>Page</u>
Data System Trade Studies	58
Accelerometer Design Study	58
Analog vs Digital Data Comparison	60
Experiment Design Trade Studies	62
Equipment On vs Off Centrifuge	62
Torque Compensation	63
Canister Shape	65
Centrifuge Beam Structure	68
Centrifuge Configuration	68
Centrifuge Mounting	72
Materials of Construction	72
Experiment Design Options	76
Negative Receptor Field Testing	76
Specimen Positioning	76
Tilt Axis Accelerations	76
Morphological Studies	77
Efferent Blocking	77
Linear Acceleration	79
Addition of Two Orbiting Control Specimens	79
Cost of Experiment Options	79
PRELIMINARY DESIGN	81
Acoustic Noise Protection	81
Centrifuge Design	84
Centrifuge Mount	84
Drive Hub Assembly	88
Centrifuge Frame	89
Canister Support Structure	89
Specimen Canister	90
Centrifuge Guard	91
Centrifuge Dynamic Model Analysis	93
Centrifuge Balancing	100
Assembly/Base Mount Flexibility	102
Assembly Rigid Body Deflection	103
Assembly Elastic Deflection	105
Combination of Induced Accelerations	107
Specimen Canister/Gimbal Assembly Weight Balance Assembly	108

	<u>Page</u>
Centrifuge and Canister Control System	109
Control Requirements	112
Servo System Description	112
System Characteristics	116
Centrifuge Torque Motor Sizing	118
Canister Torque Motor Sizing	124
Experiment Microcomputer	131
Software Design	131
Hardware Design	151
Life Support System	156
System Operation	161
Thermoelectric Unit	166
Thermoelectric Unit Controller	169
Lung	171
Baralyne Bed	172
Liquid Accumulator	174
Air Pump	177
Circulating Pump	178
Wash Pump	181
Oxygen Tank	181
Filter Assembly	181
Oxygen Pressure Regulator	183
Water Tank	185
Oxygen Partial Pressure Sensor	185
pH Sensor	185
Pressure Transducers	187
Data System	189
Data System Operation	195
Data System Control - Internal	200
Data System Control - External	202
VFR Data System Hardware	206
CDMS to VFR Data System Interfaces	206
Biological Data Grounding and Shielding	206
Instrumentation (Transducers)	226

	<u>Page</u>
Electrical Power System	226
Rack Mounted Equipment	234
Life Support Drawer (Mid Deck Transporter)	234
Middle Drawer (Fixed Life Support and Control Frogs)	239
Data System Drawer	241
Mid Deck Installation	243
VFR Experiment Weight Summary	245
Mission Operations	248
Experiment/Spacelab/Shuttle Timelines	248
Ground Support Equipment Requirements	252
Operations Plan	258
VFR Experiment Personnel Requirements	262
STS Onboard Equipment Requirements	264
EXPERIMENT EQUIPMENT COST ESTIMATE	266
Cost Elements	266
Work Breakdown Structure (WBS)	266
Schedule	269
Program Management Networks (PMN)	269
Program Requirements List	275
Cost Summary	275

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Centrifuge Assembly	4
2	Spacelab Rack Mounted Equipment	5
3	Spacelab 3	12
4	Spacelab 3 Long Module Starboard Side View	13
5	Spacelab 3 Pallet Side View	15
6	Center Aisle Interfaces - Structural, Electrical, and Data	16
7	H ₂ O and Freon 21 Coolant Loops	19
8	Spacelab/Pallet Data Interface	21
9	Pallet Dimensions - Structural Interface	22
10	Pallet Payload Clamp Assembly	23
11	Spacelab Experiment - End-Cone Mount	25
12	Spacelab Experiment - Between Last Racks	26
13	Spacelab Experiment - Center Aisle Mount	28
14	Spacelab Mounted VFR Experiment	29
15	Pallet Mounted VFR Experiment	29
16	Mission Analysis - Preflight	31
17	Mission Analysis - On Orbit	34
18	Mission Analysis - Post Landing	36
19	Spacelab Load at T-6 and GSE Transporter	42
20	12 Frog Ground Transporter	46
21	4 Frog Mid Deck Transporter	47
22	Fresh Water Required vs Urea Concentration	50
23	Concept 4 Analog/Digital Data System Experiment Recorder	61
24	Torque Compensator Size and Weight	66
25	Torque Compensator Design - Single Motor	67
26	Centrifuge Concepts - 90° Table	69

LIST OF ILLUSTRATIONS (continued)

<u>Figure</u>		<u>Page</u>
27	Centrifuge Concepts - 180° Opposed Side by Side	70
28	Centrifuge Concepts - 180° Opposed Top to Bottom	71
29	Morphological Study - System Design	78
30	Canister Configurations for Acoustic Tests	82
31	Centrifuge Assembly	85
32	Specimen Canister and Gimbal Assembly	86
33	Centrifuge Drive Hub Assembly	87
34	Centrifuge Guard	92
35	Configuration of Dynamic Model	94
36	Critical Dynamic Motion	96
37	Defining Forcing Function	97
38	Results of Forcing Functions	99
39	VFR Centrifuge Assembly	101
40	Canister & Gimbal Balance Weight Locations	110
41	Experiment Control System	111
42	Centrifuge and Canister Servo System	113
43a	Centrifuge Rate Servo	115
43b	Canister Position Servo Block Diagram	117
44	Angular Acceleration and Motor Torque Required for Linearly Increasing g During Centrifuge Spinup	120
45	Centrifuge Linear Acceleration vs Time for Ideal and Actual Case	121
46	Canister Tilt Angle vs Time for Equivalent Spin Cycle	126
47	Required Canister Tilt vs Torque Motor Capabilities	127
48	Tilt Motor Torque Required vs Constant "G" Before Tilt	129
49	Program Flowchart	132
50	Prelaunch Program Flowchart	133
51	Programmed Event Generation	135
52	Main Program Flowchart	138
53	Interrupt Program	139
54	Main Program Stack	140

LIST OF ILLUSTRATION (continued)

<u>Figure</u>		<u>Page</u>
55	Stack Operation	142
56	Event Words	143
57	Spin Cycle, Rate vs Time Table	145
58	Spin Cycle Flow Chart	147
59	Memory Map	152
60	Microcomputer Block Diagram	153
61	Microcomputer - Mechanical	158
62	Life Support System Schematic	159
63	Thermoelectric Unit	167
64	Thermoelectric Unit Controller	170
65	SCI-MED Kolobow Membrane Lung	173
66	Baralyne Bed	175
67	Liquid Accumulator	176
68	Air Pump	179
69	Circulation Pump	180
70	Wash Pump	182
71	Filter	184
72	Oxygen Partial Pressure Sensor	186
73	Data Acquisition Profile	196
74	Data Acquisition System	197
75	Data System Control	201
76	Data Control Mode Utilization	203
77	Data Control Modes and Equipment Function	204
78	Experiment Data Control Loop	205
79	Biological Signal Conditioning Assembly	210
80	Bio-Signal Conditioning Power Supply	211
81	Accelerometer Signal Conditioning	212
82	Temperature and PO ₂ Signal Conditioning	213
83	LSS Signal Conditioner Assembly Features	214
84	Experiment PCM Multiplexer/Encoder	215
85	Experiment PCM Multiplexer/Encoder - Outputs	216

LIST OF ILLUSTRATIONS (continued)

<u>Figure</u>		<u>Page</u>
86	Format Detail Analog Data Cycle (128 Frames)	217
87	Experiment PCM MUX-Format Detail	218
88	Centrifuge VCO Assembly Features	219
89	Rack VCO Assembly	220
91	Life Support System Data Submultiplexer	222
92	Control PCM Multiplexer/Encoder Features	223
93	VFR Tape Recorder Features	224
94	Grounding and Shielding of Bio Data	225
95	Electrical Power Distribution System	228
96	Experiment Battery	229
97	Electrical Power Profile	233
98	Rack Mounted Experiment Equipment	235
99	Life Support Installation (Mid Deck Transporter)	237
100	Fixed Life Support and Control Frog Canister Installation	240
101	Data System Installation	242
102	Mid Deck Installation	244
103	Prelaunch Operations	249
104	On Orbit Operations	251
105	Pre-reentry Operations	251
106	Postlanding Operations	253
107	VFR Experiment Personnel Requirements	263
108	VFR Work Breakdown Structure (WBS)	267
109	VFR Experiment Schedule	270
110	Program Management Network (PMC) - Program Management	271
111	Program Management Network - Manufacturing, Assembly and Test	273
112	Program Management Network - Mission Operation	274

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Spacelab Versus Pallet-Mounted Experiment	37
2	Specimen Loading Options	44
3	Specimen Unloading Options	45
4	Specimen Ground Handling	49
5	Thermal Control Comparison	57
6	Accelerometer Concepts	59
7	Materials of Construction	73
8	Non-Metallic Materials Selection	74
9	Weight Summary for Dynamic Module Analysis	95
10	Microcomputer Parts List*	157
11	System Liquid Pressure Drop Summary	162
12	Heat Load Summary	164
13	Life Support System Power Summary	165
14	System Pressure Transducers	188
15	VFR Measurement and Data Acquisition Requirements	190
16	Data System Hardware Summary	207
17	Transducer Descriptions	227
18	Electrical Power Summary	231
19	Life Support System Weight Summary	238
20	Weight Summary - Rack Mounted Equipment	245
21	STS On Board Equipment	264
22	VFR Experiment Equipment	276
23	Assurance/Testing Criteria	281
24	Documentation Requirements Comparison	282

INTRODUCTION AND SUMMARY

The Vestibular Function Research (VFR) Experiment has been established to investigate the neurosensory and related physiological processes believed to be associated with the space flight nausea syndrome and to develop logical means for its prediction, prevention and treatment. The occurrence of space nausea in Skylab was greater than anticipated and concern over the effect on STS flight crews led to the establishment of the VFR Project.

The VFR Project consists of ground and spaceflight experimentation using frogs as specimens. Frogs have been selected because they are known to be responsive to vestibular stimulation, they are small enough to be practical for space flight, and their otolith system is similar to that in man. Microelectrodes implanted into the eighth nerve of the frog provide for recording of the otolith, semicircular canal and vibration afferents. Four frogs are mounted in canisters and placed on a centrifuge, so that the frogs can be exposed to zero-gravity and artificial gravity environments. The centrifuge and rotatable canisters are used to provide stimulus to the otolith by providing a variety of different motions. A life support system provides for water circulation, solids removal, urea removal, oxygenation of the water, carbon dioxide removal, bacterial control, thermal control, specimen feeding and removal of dead skin from the frog's body. Specimen biological and system housekeeping data are collected and recorded on-board the Space Shuttle vehicle and are transmitted to the ground for processing and review.

The Phase B Preliminary Design Study provided for the preliminary design definition of the experiment hardware, preparation of performance and hardware specification and a Phase C/D development plan, establishment of STS interfaces and mission operations, and the study of a variety of hardware, experiment and mission options. The study described by this report consisted of

three major tasks:

- o Mission Mode Trade-off
- o Conceptual Design
- o Preliminary Design

During the mission mode trade study two experiment locations were compared, i.e., location on the unpressurized pallet in the Space Shuttle payload bay and location in the pressurized Spacelab Module. The advantages and disadvantages of each approach were established with respect to complexity of equipment design, accessibility for loading and unloading specimens, STS interfaces, cost and other factors. Location of the equipment in the aft cone area of the Spacelab module was selected as the preferred design.

The conceptual design study investigated alternate means of accomplishing the experiment and meeting experiment requirements. Alternate sub-system approaches for both inflight and ground support equipment were defined as well as alternate means of accomplishing mission operations. A number of experiment options were also studied during this period including cost estimates for each approach. The conceptual design study provided the basis for the preliminary design that was to follow. Important conclusions reached at this point in the study were the:

- o Desirability of specimen loading at launch minus six hours into the Spacelab Module
- o Need for a multi-frog ground transporter to support transfer of the specimens
- o Use of a digital data system with an analog-digital on-board experiment recorder
- o Definition of the centrifuge configuration and canister design concept.
- o Selection of simplified state-of-the-art life support system
- o Selection of experiment options that called for addition of two control frogs located in the Spacelab rack, and the ability to manually position each specimen prior to centrifugation.

The preliminary design task continued work begun earlier in the study with respect to dynamic analysis of the centrifuge structure and acoustic noise

attenuation and provided the end result of the study; the preliminary design definition of the experiment. Figures 1 and 2 present the centrifuge design and the Spacelab rack mounted equipment layout, respectively. The centrifuge design provides for mounting of the frogs, canister mounting and positioning in all three axes, acoustic noise protection of the specimens, thermal isolation, data acquisition signal conditioning and formatting, automatic operation of the centrifuge and canister tilt control system to a preprogrammed schedule, specimen feeding, and attachment to the Spacelab floor. The rack mounted equipment includes the life support equipment, two control specimens, tape recorder, data handling equipment, electrical power distribution system and experiment battery. Included in all three study tasks were the definition of the development plan and estimates of program costs for the C/D Phases.

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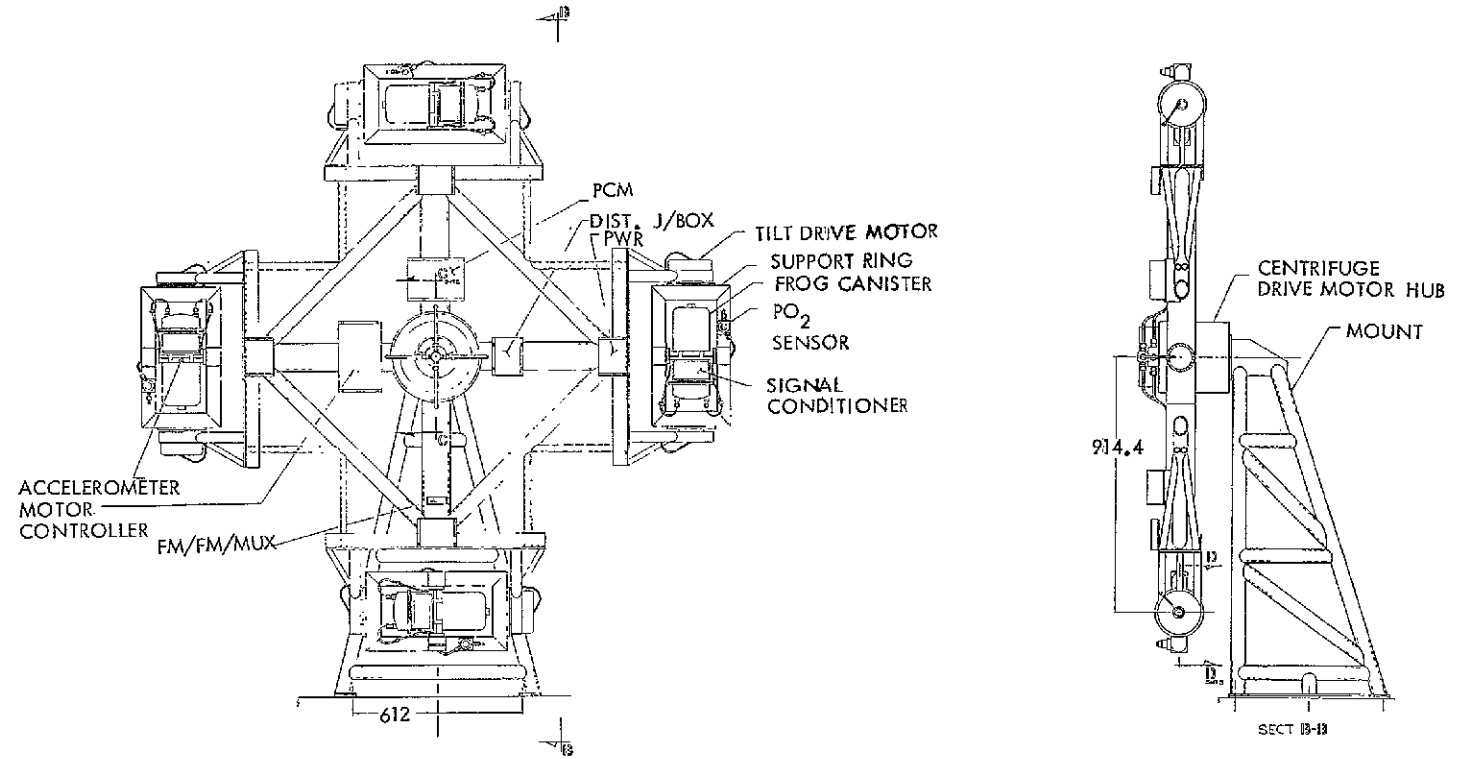


Figure 1 Centrifuge Assembly

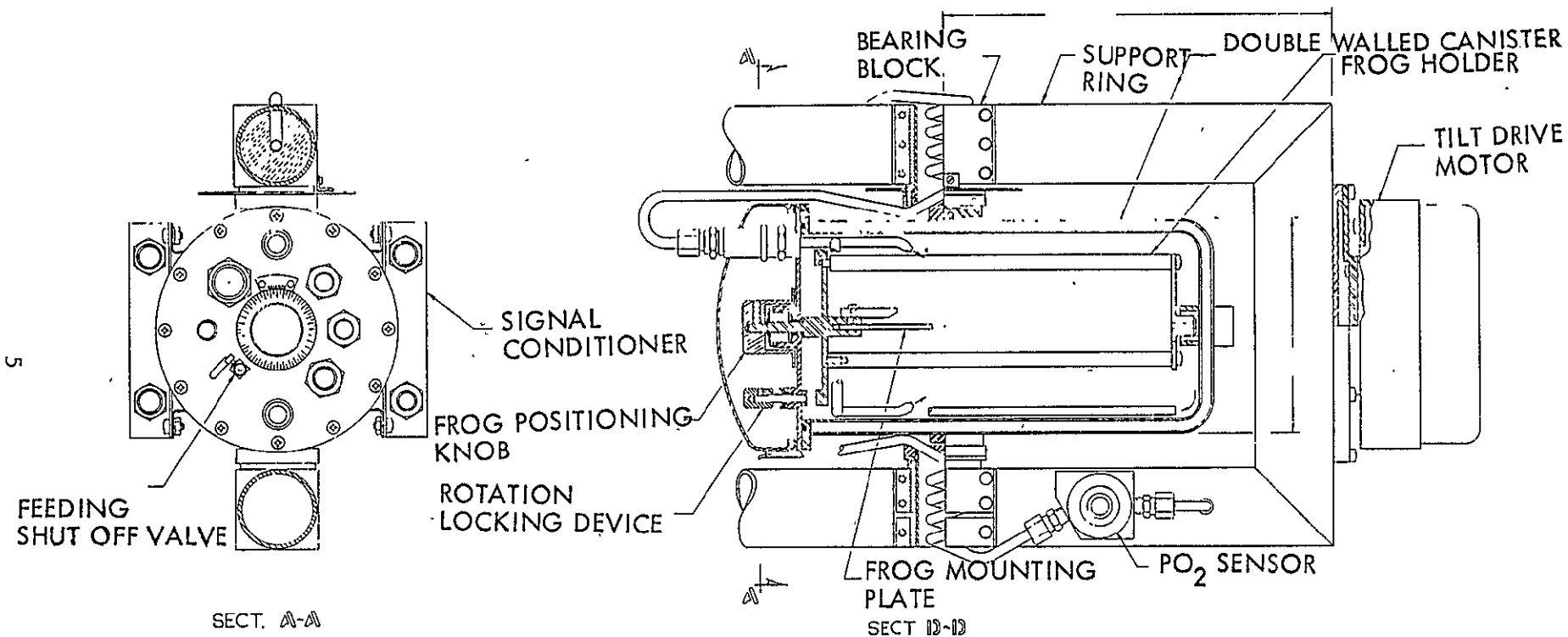


Figure 2 Specimen Canister and Gimbal Assembly

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EXPERIMENT REQUIREMENTS

Experiment requirements are specified by subsystem as follows:

- o Specimen Canisters
- o Centrifuge/Canister Stimulus
- o Life Support
- o Control and Data Management
- o Electrical Power

Specimen Canisters

Each 350 gm frog specimen shall be restrained in a liquid tight canister containing a 1/100th Ringers solution. Fluid flow, and temperature control shall be as specified in the life support section. Specimen instrumentation wiring, grounds and feeding tubes shall pass through separate adequately sealed connectors.

Four canisters shall be mounted on the centrifuge in a multi-axis gimbal assembly and two will be rack mounted without gimbals. Materials used shall not be toxic to the specimens or react with each other causing undesirable results.

Acoustic noise level shall not exceed 100 db at the frog specimens head.

Centrifuge/Canister Stimulus

The centrifuge and gimbal assembly shall be capable of providing the following acceleration levels and specimen orientation:

- o Centrifuge radius from the center of the rotating hub to the center of the specimens head shall be at least 3 feet.

- o Single and multiple spin cycles with preprogrammed and programable spin up and spin down. Spin-up from 0 to 0.3 g shall be accomplished in 8 seconds and shall be linear within .01 g, followed by 60 seconds at 0.3 g, followed by linear drop to 0 g in 14 seconds.
- o Constant artificial g, selectable from 0 g to 1 g ($\pm 10^{-3}$ g) in 0.05 g increments.
- o Manual specimen positioning in all three axes through $\pm 180^\circ$ prior to centrifugation.
- o Equivalent spin-up and spin-down shall be provided whereby the specimens are positioned at 90 degrees, then subjected to a constant artificial gravity, forward tilting the specimen to a predetermined angle during which acceleration is increased and finally reversing the tilt to its original position while simultaneously reducing the centrifuge acceleration to its original value. Equivalent spin cycles shall be started from any steady "g" value from 0 to 1 g and shall provide the resultant force vector at the proper angle and magnitude of that steady "g" value plus a changing "g" from 0 to 0.3 g to 0 g acting at right angles to the steady "g". Specimen canisters shall be positioned to a 90 degree position prior to equivalent spin, tilted downward to produce the equivalent force angle, and returned to 90 degrees during de-spin.
- o Extraneous acceleration levels during both centrifuge spin cycles and at rest will not be allowed to exceed 10^{-3} g.

Life Support

The life support system shall have the capability of providing oxygen to and removing carbon dioxide from the frog solution and providing solid and liquid waste management, filtration and bacterial control, thermal control and feeding for a basic eight day orbital mission with a 50 percent reserve on all expendables. It will specifically be capable of accomplishing the following:

- o Maintain the oxygen level of the frog water to a minimum of 650 mm Hg.

- o Maintain the specimen water temperature at 62 ± 2 degrees F at all times.
- o Provide urea control with a maximum level of 50 ppm. The urea production rate is 40 mg/Kg of frog/day, and each frog will weigh approximately 350 gm.
- o Provide frog washing for skin removal with fluid flow through each canister at a 0.5 gpm rate for 20 minutes two times per day.
- o Provide an environment of Ringers solution diluted 100 times with distilled water. Ringer solution in gm/liter is NaCl = 6.5, KCl = 0.14, CaCl_2 = 0.12 and NaHCO_3 = 0.1. Circulation through each canister will be 500 cc/min.
- o Provide capabilities of increasing the liquid O_2 pressure to 1003 mm Hg which will allow disruption of the oxygen supply for 0.7 hours without the oxygen partial pressure decreasing below 650 mm Hg.
- o Accomplish CO_2 removal from the liquid, which is produced at approximately 50 cc/hr/frog.
- o Solids shall be removed down to 40 micron nominal size.
- o Frog feeding will be accomplished twice during the 8 day mission at a rate of 8 cc/350 gm frog per feeding via the implanted .5 mm ID tube surgically implanted in the ventral or dorsal lymphatic sac.

Control and Data Management

Commencing with specimen loading, acceleration data shall be continuously recorded from one frogs head mounted triaxial accelerometer (± 1 g, .001 g sensitivity and 0 to 250 Hz) and from the frame mounted triaxial accelerometer (± 5 g, .1 sensitivity and 0 to 500 Hz).

Periodically all data shall be recorded for 15 minutes, four times per day from loading until launch. After spacelab activation, all data will be downlinked with periodic data recorded by the experiment recorders. Continuous acceleration data from one frogs head mounted accelerometer will be transmitted in the Ku-band downlink.

The following biological and accelerometer measurement characteristics are required.

<u>Measurement</u>	<u>Bandwidth (Hz)</u>	<u>Number of Channels</u>	<u>Range</u>	<u>Sensitivity</u>	<u>Accuracy</u>
Otolith	1800*	12**	-	-	$\pm 1\%$
EKG	200	6**	-	-	$\pm 1\%$
Accelerometer (Frogs Head)	DC to 250	18**	$\pm 1g$	0.001	-
Accelerometer (Canister)	DC to 250	3	$\pm 1g$	0.001	-
Accelerometer (Frame)	DC to 600	3	$\pm 5g$	0.01	-

*5 samples/cycle digital sampling rate

** 2/3 monitored during normal data scan, 1/3 at other times

Data will not be required from the time that the Spacelab is deactivated, though specimen transfer to mid-deck and until 2 hours after touchdown.

PO₂ sensor data is required for each frog specimen.

Data will be acquired 14 minutes before, during and 14 minutes after each spin cycle or series. The two rack mounted frogs may be monitored when the other four centrifuge mounted frogs are not being monitored.

The otolith data shall be recorded in analog by the experiment recorder but may be digitized for transmission to the ground. All other data may be recorded in a digital format.

During transport of the specimens from the PI's laboratory to KSC continuous acceleration data will be recorded of a frame mounted triaxial accelerometer ($\pm 5g$, .1 g sensitivity and from 0 to 500 Hz). From the MSOB to Spacelab loading on the centrifuge continuous acceleration data will be recorded from the frame mounted accelerometer and from one frogs head mounted accelerometer ($\pm 1g$, .001 g sensitivity and 0 to 250 Hz).

Electrical Power

All flight hardware requiring electrical power must be capable of operating from a 28 ± 4 Vdc power source.

Ripple and noise on the electrical power bus will be as specified in SLP/2104 Appendix A.

Front panel control shall be provided for rack and centrifuge power and also for the inhibit capability for the tape recorder and centrifuge/tilt motors.

Power for the individual components (i.e., multiplexers, power supplies, tape recorder) will be automatically controlled by the microcomputer according to the programmed instructions. These components will be turned off during periods in which they are not needed to conserve orbiter supplied power and reduce the Spacelab heat load.

MISSION MODE TRADEOFF

The first task in the Phase B Preliminary Design Study was mission mode trade-off which compared Pallet and Spacelab mounted experiment locations. This task was initiated with a review of the Spacelab systems to establish the Spacelab configuration, interfaces, mission operations and environments with respect to pallet and module. Both pallet and module mounted experiments were then configured based on preliminary estimates of subsystem size, weights and power consumption and mission operations. The configurations were compared and a selection was made. A document entitled "Mission Mode Trade-off Report" LMSC-D566552 dated 10 January 1978 was prepared to present the results of the trade-off. The work presented in that report is summarized, herein. For added detail on the results of the mission mode trade-off task the reader is referred to the more detailed report.

Spacelab Systems

Important in the selection of the VFR mission mode are the structural, electrical, cooling and data interfaces and the integration of the experiment operations into the space shuttle mission timelines. This portion of the report covers space shuttle and spacelab systems.

Spacelab Configuration

Spacelab consists of two basic elements - a pressurized module and an unpressurized pallet - which can be used separately or in combination. For this study we used the Long Module plus 3 meter Pallet Configurations which is compatible with both mission modes.

Spacelab III is a potential carrier for the VFR experiment. Figure 3 shows the Long Module plus 3 meter Pallet Configuration and Figure 4 shows the

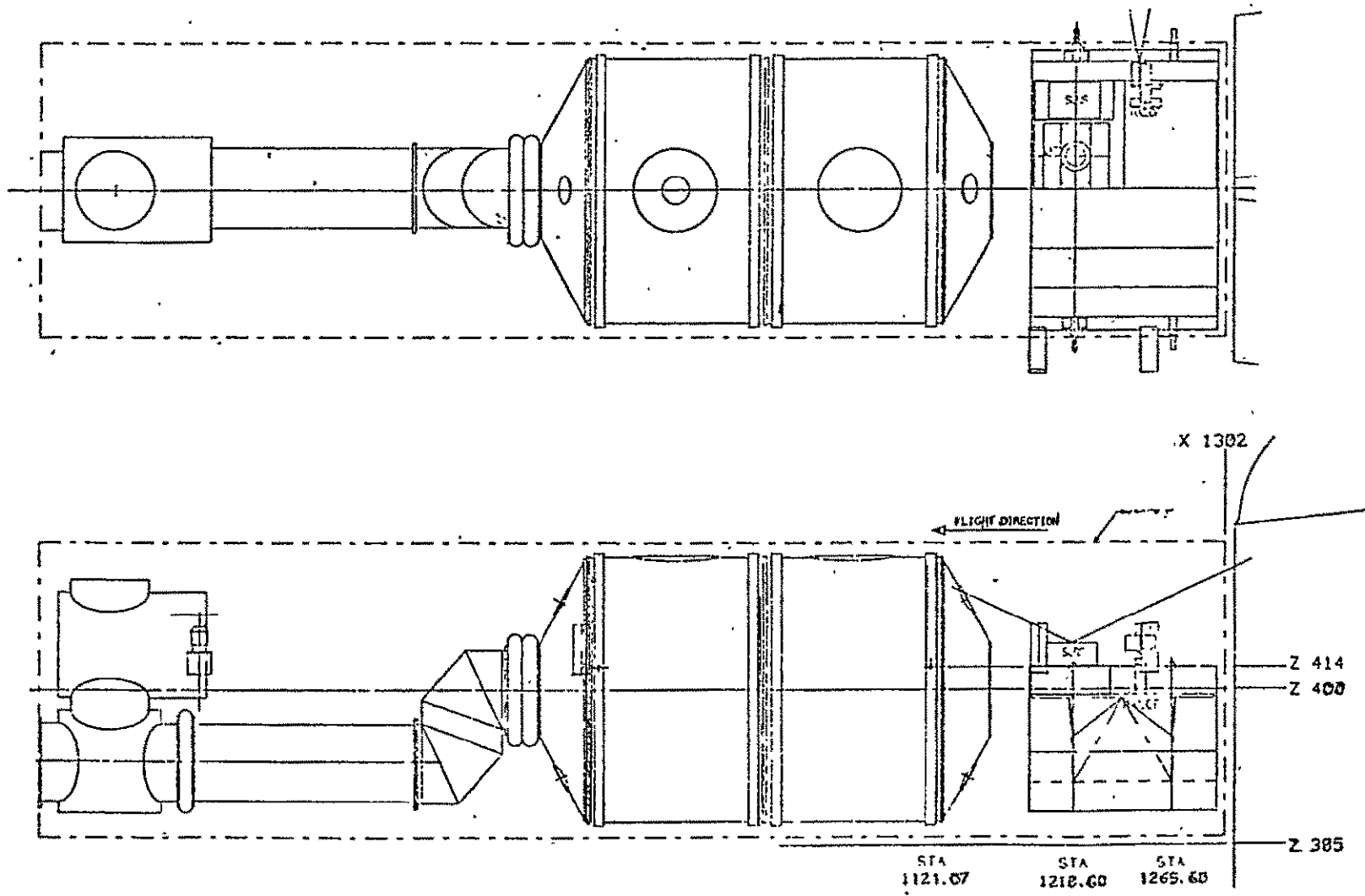


Figure 3 Spacelab 3

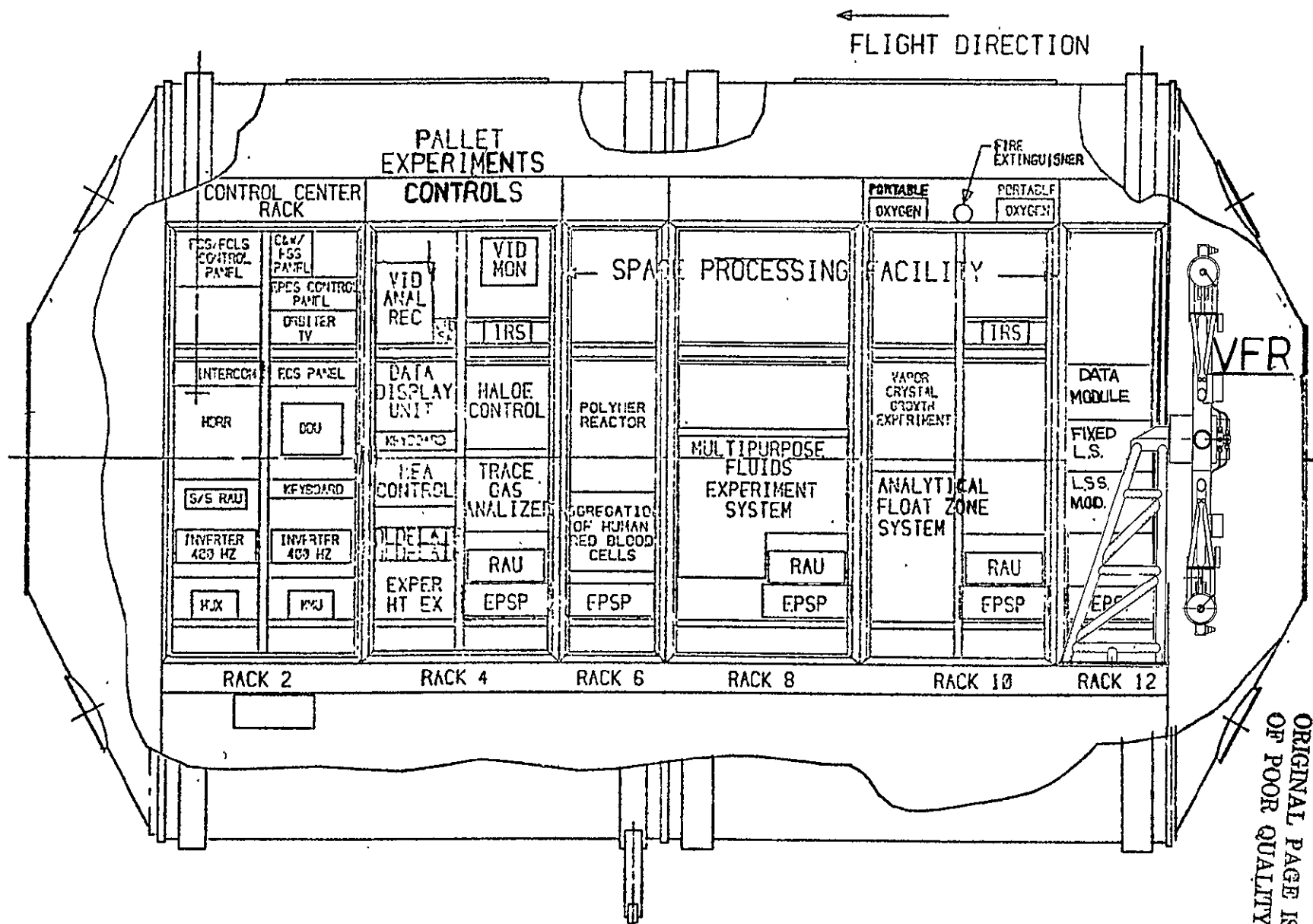


Figure 4 Spacelab 3 Long Module Starboard Side View

interior layout of Spacelab III module and a concept for the VFR experiment location and mounting. Figure 5 shows a side view of two payloads mounted on the Pallet (SGRS and HALOE). The space and pointing/viewing requirements of the SGRS, HALOE, and LFC payloads would virtually eliminate carrying the VFR payload on the pallet.

Spacelab Interfaces

In evaluating the Pallet vs Module centrifuge location, four Spacelab interfaces have been identified which impact the final selection.

- o Structural (centrifuge and support equipment mounting and envelope constraints)
- o Electrical (available power, quality and anticipated mission profile)
- o Cooling (available heat exchangers, cold plates and expected temperatures with respect to the mission profile)
- o Data (processing and/or preconditioning required by experiment hardware)

The characteristics of the interfaces are discussed in the following paragraphs as they apply to the pallet and module

Spacelab Module Interfaces

For the module location, the aft area has been selected in order to eliminate any interference with the ingress/egress of the crew via the tunnel or obstruct free movement of the crew within the module.

The dimensions from rack to rack ($\approx$ 2134 mm, 7.0 ft) and floor overhead storage ($\approx$ 2175 mm, 7.13 ft) indicate a centrifuge diameter limit of approximately 7 feet.

Structural - Figure 6 shows the center aisle mounting interface and details as well as the physical locations of the electrical, data, cabling and fluid interfaces with respect to the floor. The maximum structural load is 300 kg/m length of center aisle section. Center of Gravity (CG) limitations are to be determined at a later date.

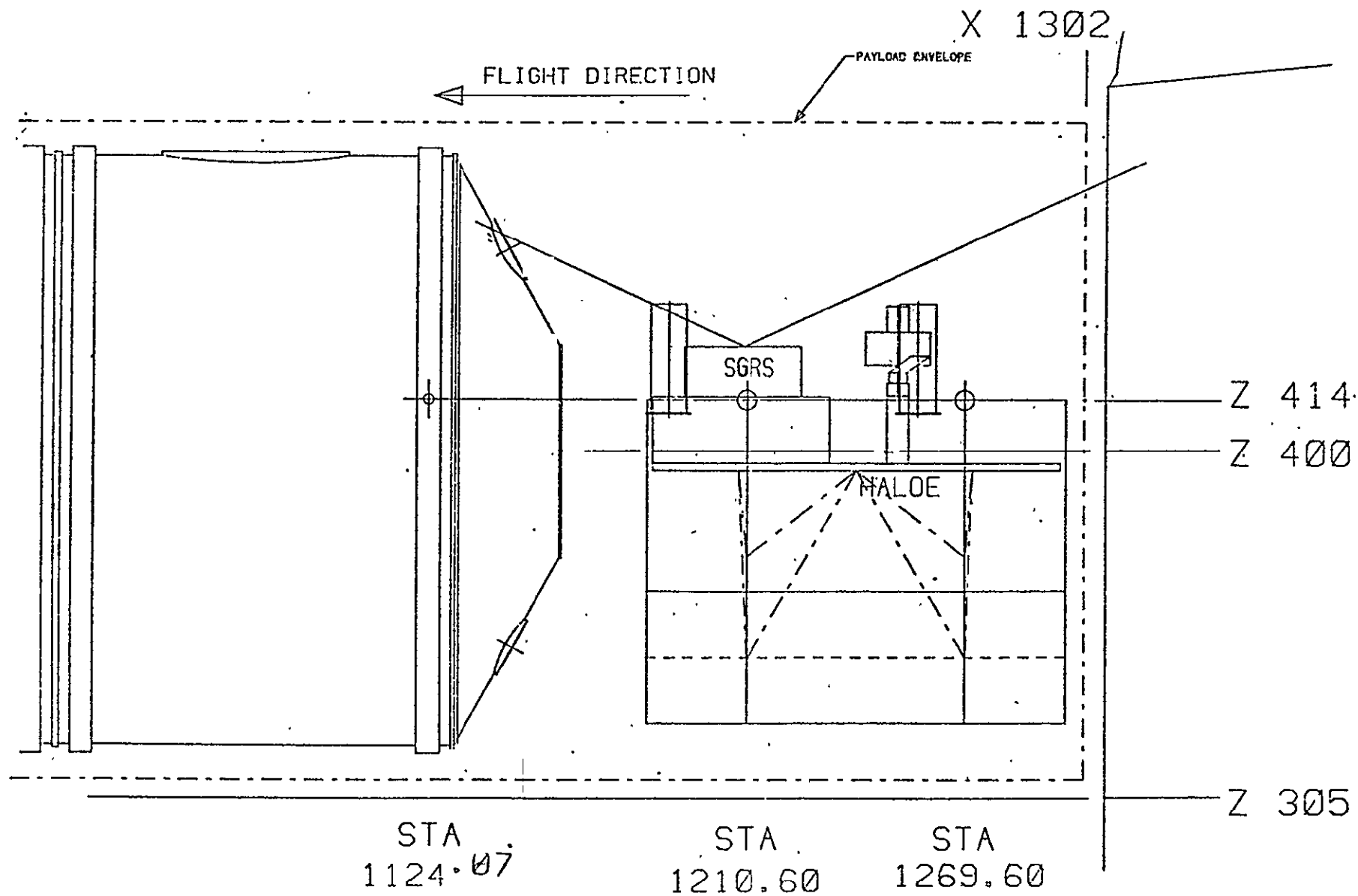


Figure 5 Spacelab 3 Pallet Side View

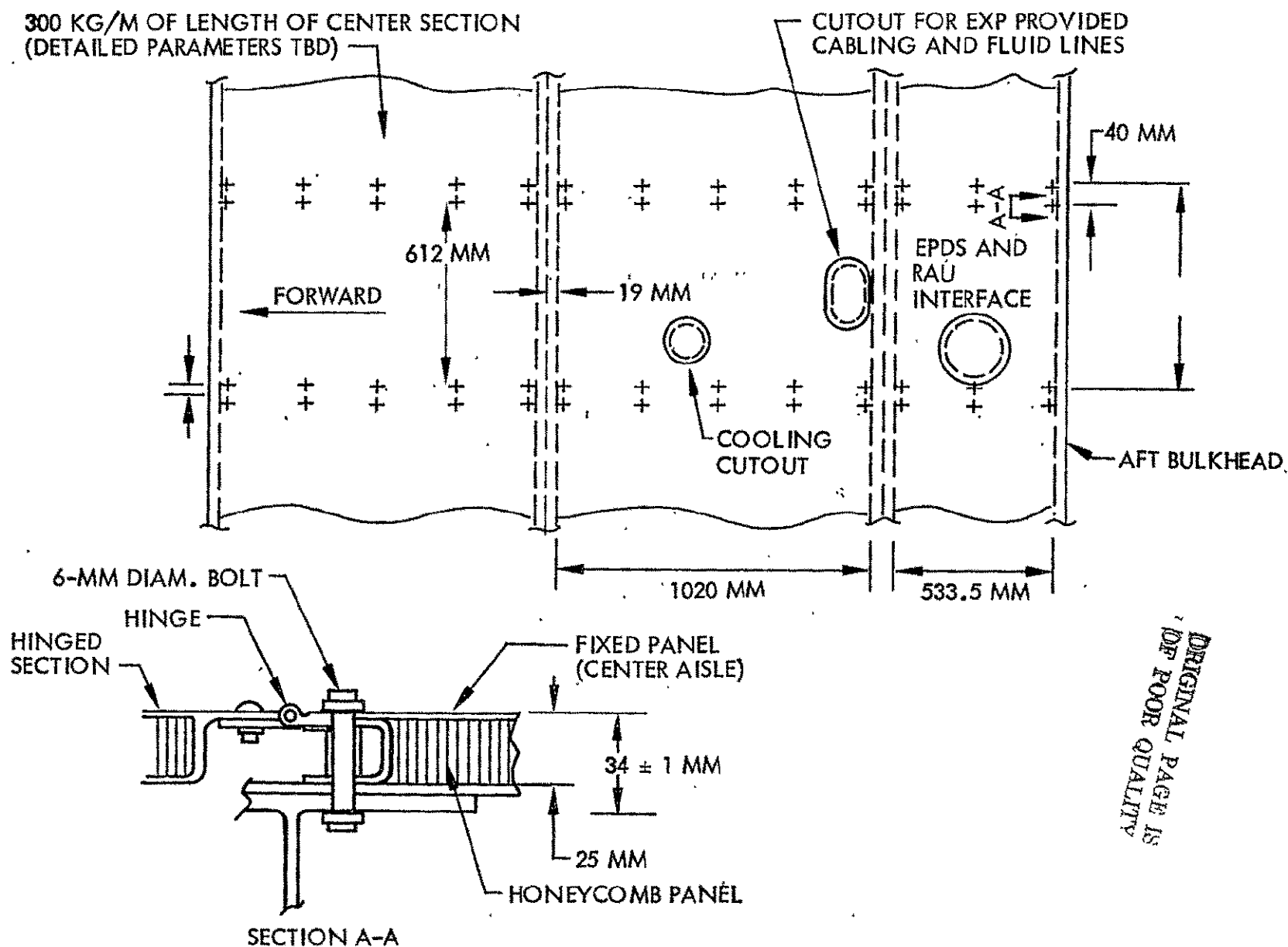


Figure 6 Center Aisle Interfaces - Structural, Electrical, and Data

Additional structural interfaces may include the aft end cone and overhead structure. Recent discussions reveal that consideration is being given to strengthening the end cone and providing experiment attachment point as a possible future change. The overhead structure interface may be considered as a mounting point if the rack(s) were not installed at the selected interface point.

Electrical - The physical interface to the Spacelab Electrical Power Distribution System (EPDS) may occur at three locations; one at the connector panel on the aft floor segment in the center aisle for an aisle mounted equipment, another in an experiment rack panel referred to as the Experiment Power Switching Panel (EPSP), and third in the under floor area at one of two Experiment Power Distribution Box's (EPDB's).

At this time power available at the interfaces discussed above is as follows:

- o Primary D.C. Power

- 28 $\pm$ 4 VDC

- 7 kw maximum continuous power available to Spacelab from orbiter in a dedicated fuel cell mode with orbiter powered down.

- During periods that orbiter is powered up, less power will be allocated to the Spacelab, however approximately 1 kw will be available at all times except for transfer periods and possible short duration interrupts. However the 1 kw may be used to routinely operate other experiments and power certain subsystem (S/S) equipment.

- o AC Power

- 115 vrms $\pm$ 5% 3 phase Wye

- 400 Hz $\pm$ 1%

- 2.7 KVA max continuous

- A.C. power used must be deducted from total primary D.C. power available to S/L. A.C. power is not available during Orbiter power up condition.

- o Experiment Essential Power
 - 22.5 to 32 VDC
 - 400 W max continuous
 - *400 W drawn from emergency box and includes total power drawn from Emergency bus, S/S Essential bus and Experiment Essential bus.

Reviewing the power profiles presented in the Spacelab and shuttle documents resulted in the following conclusions. With the orbiter on the Pad, power may be limited at various times. It is quite possible that only essential power will be available to the VFR equipment as the orbiter is powered up for pre-launch and launch. At approximately T-10 minutes power will transfer from the GSE to the vehicle. Cooling will also be reduced at this time. This condition will continue until the orbiter is powered-down at which time power is made available to the payload with the dedicated fuel cell. The power-up of Spacelab will occur at approximately T+90 to 120 minutes. Total Primary bus power to the spacelab will be = 7 kw with essential power remaining at 400 watts total for all three forementioned buses.

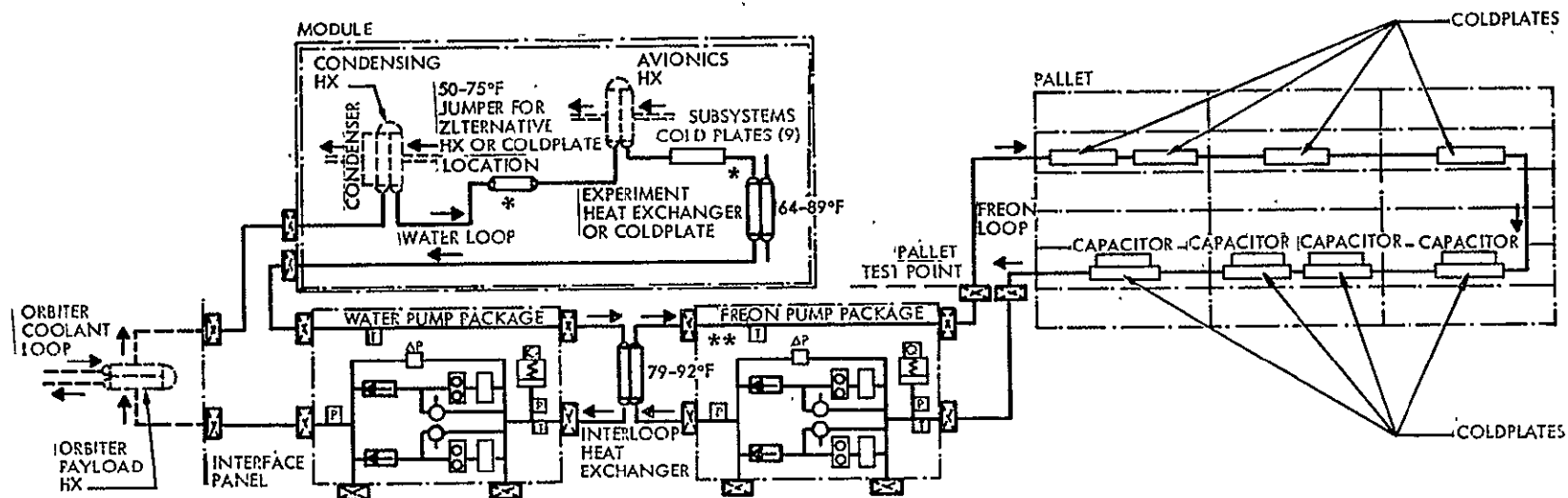
Cooling will be between 6.3 kw and 8.5 kw depending on whether the orbiter is equipped with the radiator kit or not.

Approximately 6.5 hrs. prior to touchdown the Spacelab will be deactivated in preparation for thermal conditioning and reentry. This again reduces power available to the Spacelab except for essential power. Thermal conditioning will normally last 6 hours, but may last up to 24 hours.

Within 15 minutes after touch-down, GSE cooling will be connected and simultaneous or shortly thereafter GSE power will be available.

Cooling - The principal cooling interfaces are the experiment heat exchanger experiment cold plate and the cabin air. Figure 7 presents a schematic of the Spacelab cooling system. The range of temperatures expected in the Spacelab coolant loop are shown in the Payload Accommodations Handbook and will

19



* EXPERIMENT COLDPLATE (IF REQUIRED) MUST BE CONNECTED IN SERIES WITH EXPERIMENT H-X

** ASSUMING 3-KW FREON LOOP LOAD -
(1000-W FREON LOAD = 63°F)

MINIMUM TEMPERATURE-BASED

MAXIMUM TEMPERATURE-BASED

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Figure 7 H₂O and Freon 21 Coolant Loops

vary depending on total S/S and experiment heat loads. Coolant temperatures ranging from 10°C (50°F) up to 23°C (74°F) can be expected at the experiment heat exchanger located upstream of the avionics heat exchanger.

Data - The data interface is shown in Figure 8 for the Remote Acquisition Unit (RAU) and the KU-Band 4.5 mHz wideband analog. The RAU may be mounted in an experiment rack or on the centrifuge support frame and interface at the center aisle floor connector or directly at the experiment I/O unit.

Spacelab Pallet Interfaces

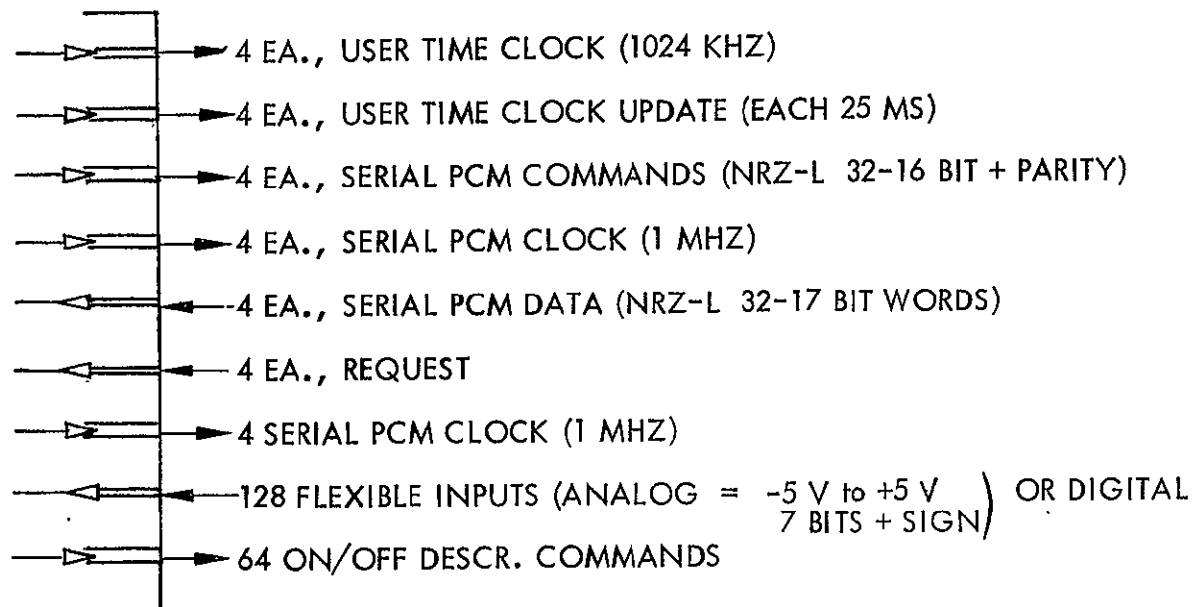
Figure 9 illustrates the pallet mounting points to which the VFR experiment hardware can be connected. The mounting can be either to the inner panel with a maximum load capacity of 50 kg/m² or to the hardpoints offering a total capacity of 1000 kg for the entire pallet. The actual hardpoints are inserted as shown in the upper portion of Figure 9; each hardpoint providing a spherical nut with a metric thread, bolted to the pallet structure. The payload envelope for the pallet is a maximum diameter of 3630 mm (142.92 in) with the center located 1840 mm (72.44 in) above the lower inner panels.

The length of each pallet is 2875 mm (113.19 in). Normally the first row of panels on each pallet contains a cold plate on which subsystems and experiment equipment is mounted, however, the hardpoints are clear and available for experiment mounting.

An additional interface is shown on Figure 10, if the Pallet Payload Clamp Assembly were used (PCA). This assembly will normally be used to clamp a payload in the cargo bay area during ascent and re-entry and offers the capability to release the payload on orbit.

Electrical - The electrical power profile is the same as outlined for the module configuration during all mission phases. Primary, essential and AC power is also the same except the essential power on the connector at the front of the pallet may vary between 21.5 to 32 VDC.

REMOTE ACQUISITION UNIT (RAU)



KU BAND
ANALOG (COAX)
(WB) 75Ω

(4.5 MHZ BAND WIDTH)

LEGEND

- DIFFERENTIAL FLOATING INPUT
- DIFFERENTIAL COMPLIMENTARY OUT
- SINGLE-ENDED OUTPUT

Figure 8 Spacelab/Pallet Data Interface

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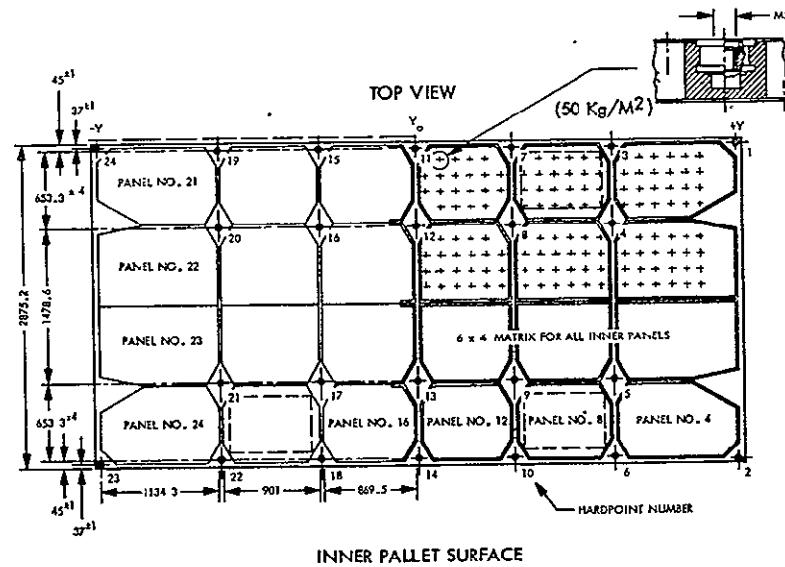
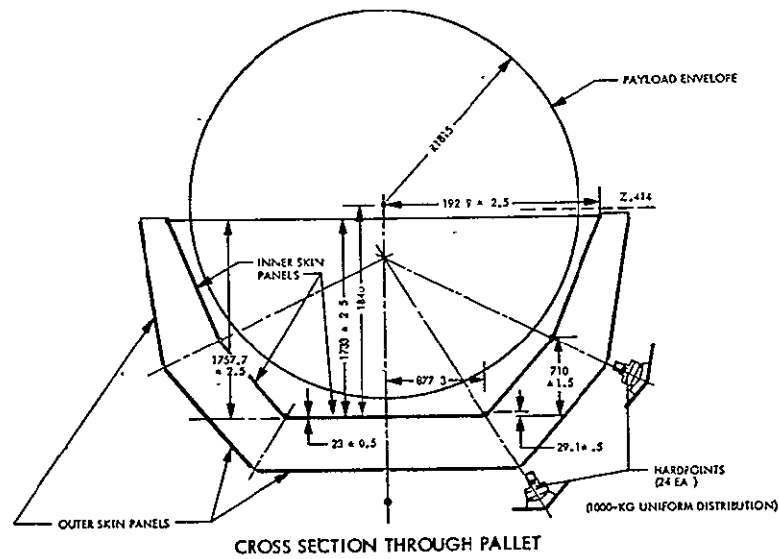


Figure 9 Pallet Dimensions - Structural Interface

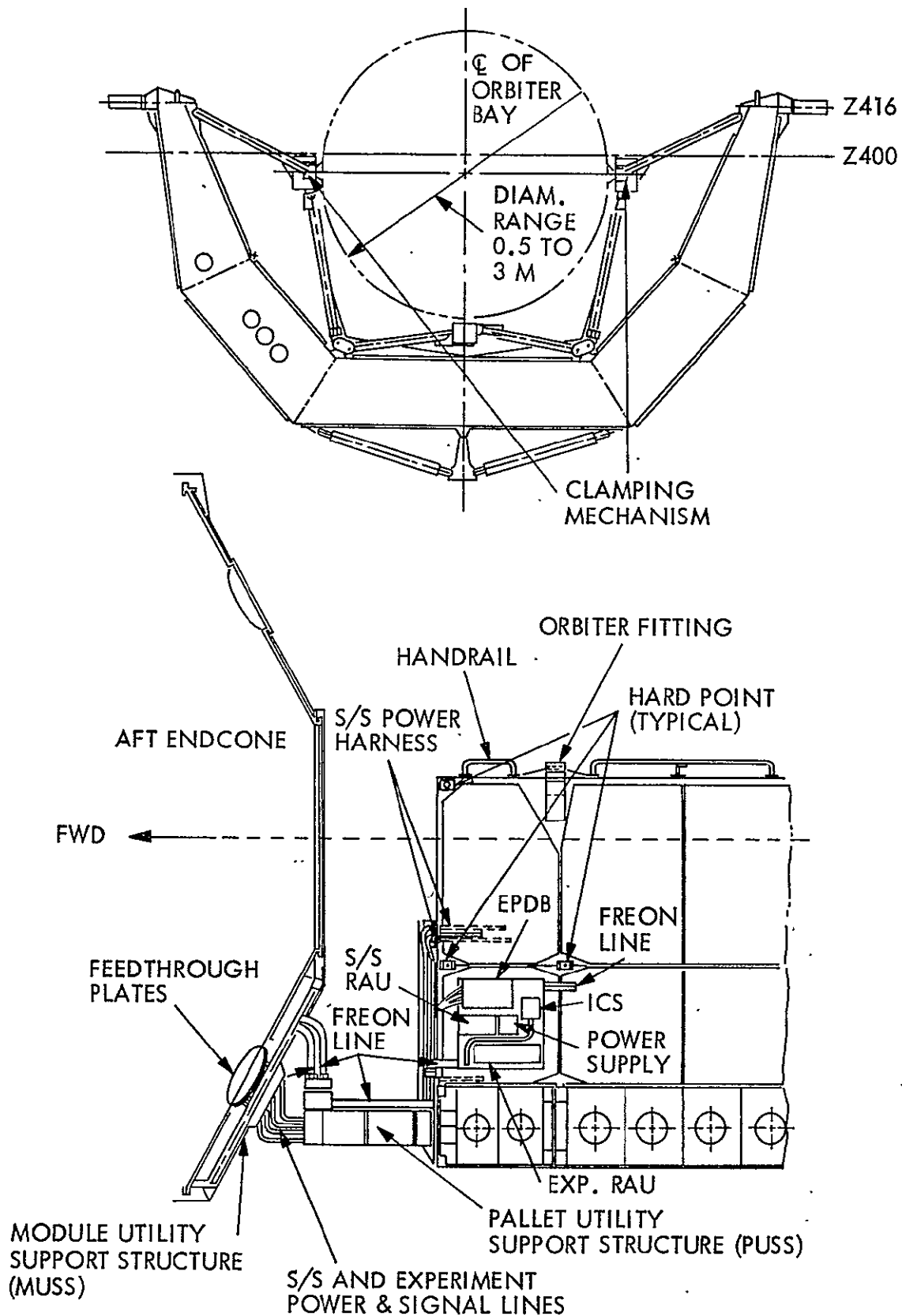


Figure 10 Pallet Payload Clamp Assembly

Cooling - The principal cooling offered by the orbiter is cold plates through which Freon 21 flows in the loop cooled via the interloop heat exchanger. Pallet coolant temperatures range from a minimum of 16°C (61°F) to a maximum of 36°C (97°F). Thermal capacitors may be provided (experiment dependent) on the pallet cold plates as shown in Figure 7.

Data - The physical data interface on the pallet is shown by Figure 10 at the Experiment RAU, which has the same characteristics as the Spacelab Module.

Spacelab Environments

Natural and induced environments that the VFR experiment equipment and specimens may be exposed to during operation within the Spacelab system are defined in the Payload Accommodations Handbook and Spacelab Accommodations Handbook. Vibration, acoustic noise, acceleration, shock, and thermal environments are defined. The reader is referred to those documents and LMSC-D566552 for details.

Spacelab Mounted Experiment

Experiment Mounting

Several concepts for the VFR experiment mounting and location in the Spacelab Module were evolved based on the preliminary subsystem and centrifuge trade studies. Figure 11 presents a VFR experiment located in the aft cone of the Spacelab Module. Two different floor mounts are shown. Attachment to the end cone would simplify the support structure and some consideration is being given by NASA to increasing the strength of the end cone to support equipment mounting. This location and mount offers the advantages of minimizing interference with other experiments in the Spacelab Module and it minimizes crew safety hazards associated with the spinning centrifuge. The disadvantages are difficulty in getting access to attach points and difficulty in rotating the centrifuge table for horizontal spinups after landing.

Figure 12 presents a centrifuge located forward of the aft end cone between the last pair of single racks. This location offers the advantages of good

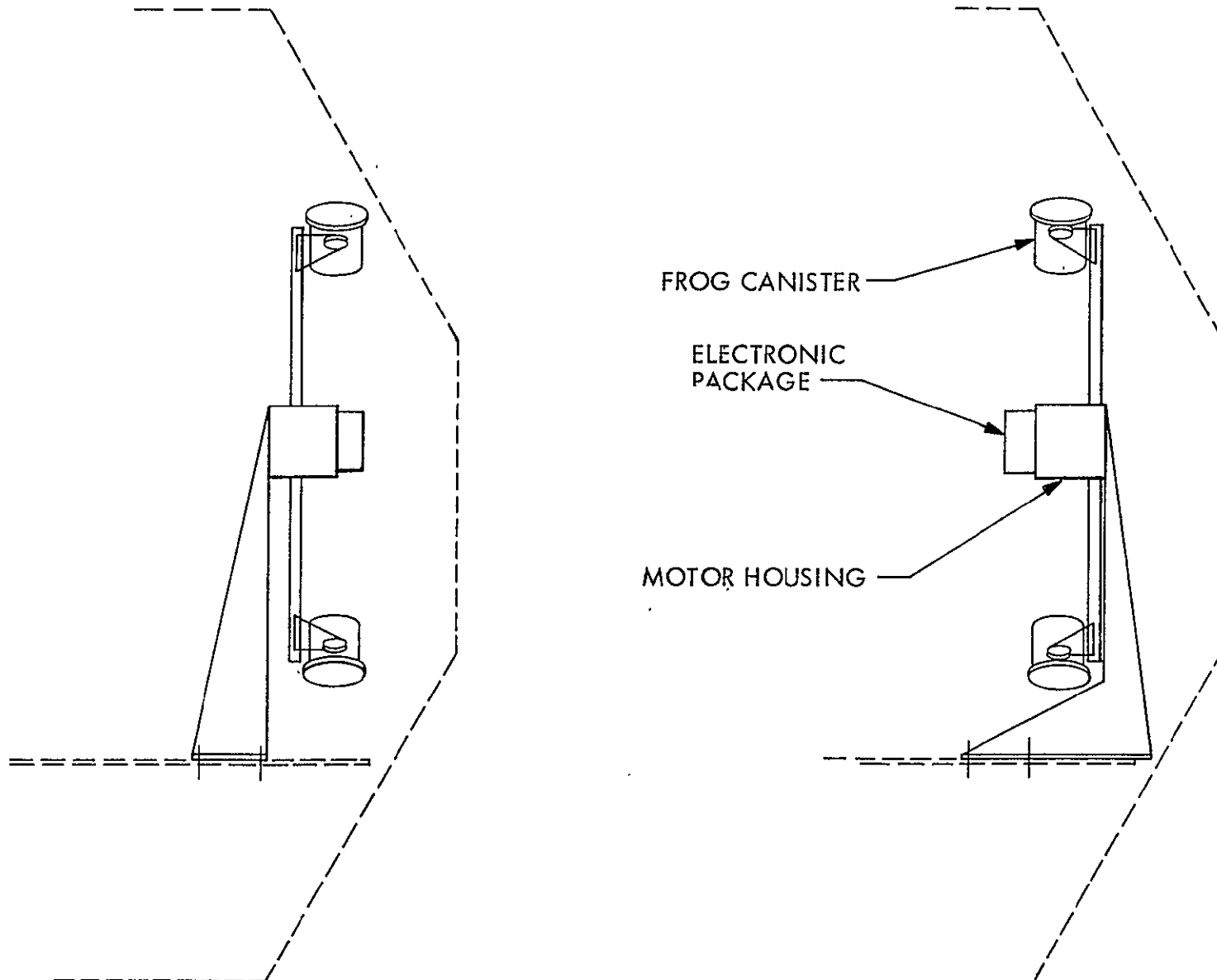


Figure 11 Spacelab Experiment - End-Cone Mount

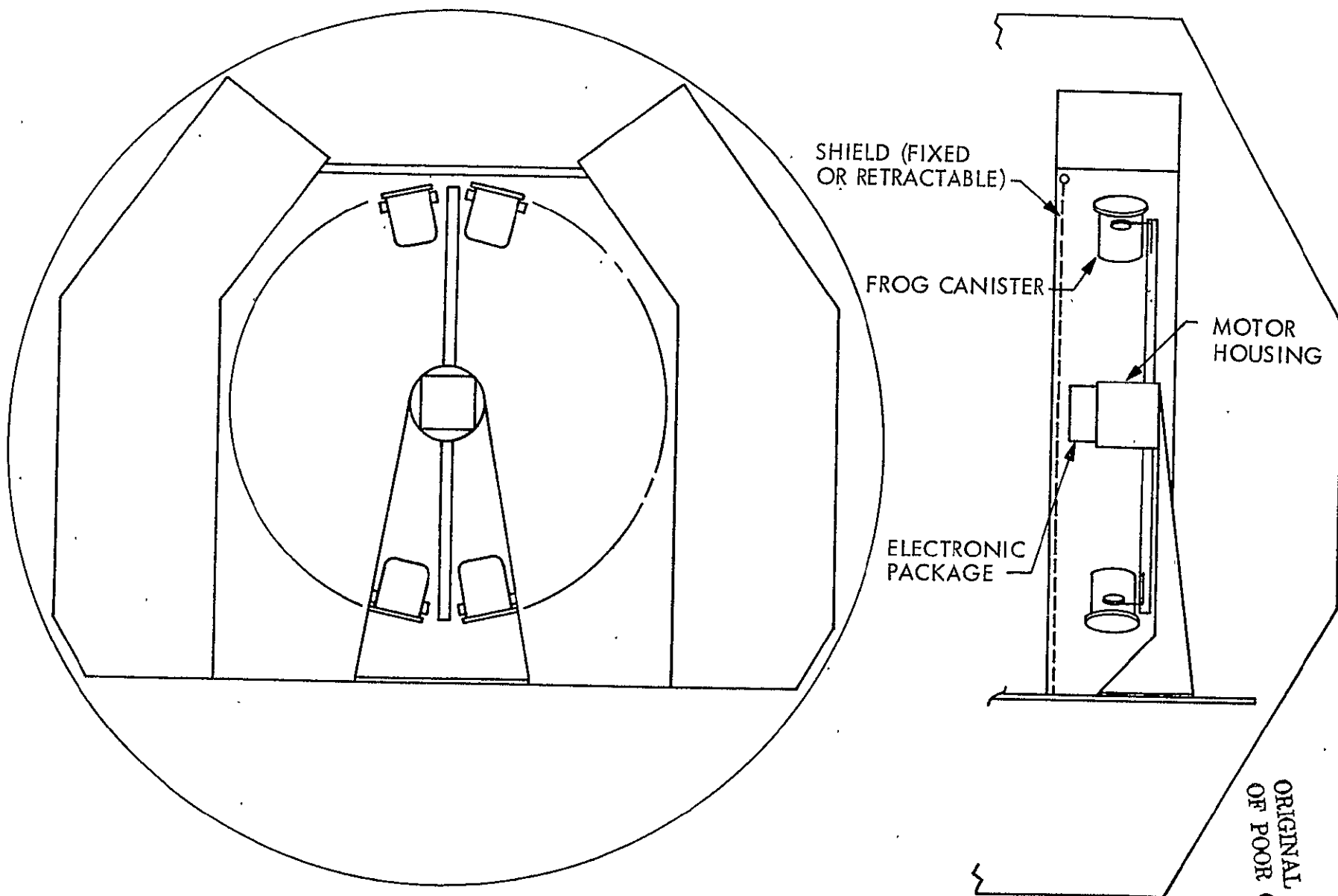


Figure 12 Spacelab Experiment - Between Last Racks

access to attach points, good access to the centrifuge components, and greater ease in positioning the centrifuge in the horizontal position for post landing spinup, if required. Disadvantages are interference with access to equipment in the last set of racks, and a greater problem with shielding the centrifuge for crew safety.

Figure 13 presents a centrifuge located down the center aisle of the Spacelab Module. This location offers good access to attach points, good access to the centrifuge components, and reasonably good access to all racks. Disadvantages are difficulty of shielding for crew safety, necessity of rotating the centrifuge for spinup in both vertical and horizontal shuttle positions, and limited interference with the last four racks. Based on the advantages and disadvantages of each concept the centrifuge location presented by Figure 11 was selected for the Spacelab Module mounted experiment.

Spacelab Module Experiment Design

An experiment design for the Spacelab Module based on the end cone location was prepared and is presented by Figure 14. The centrifuge mounts two frog canisters side-by-side on each end of a truss structure. The centrifuge provides a three foot radius from the center of the centrifuge to the center of the frogs head. A center hub contains the centrifuge bearings, drive motor, data and power slip rings, and rotary fluid joints. A tubular mounting structure supports the centrifuge from the Spacelab Module floor attach points. The data processor and electronic controller are mounted above the center hub to reduce drive motor torque and centrifuge unbalance. Support equipment not located on the centrifuge is mounted in a single ESA rack.

Pallet Mounted Experiment

An experiment design for the pallet based on a radial mounting position was prepared and is presented by Figure 15. The Payload Clamp Assembly was not used because it does not lend itself to efficient use of space and does not provide an easy connection to the hub of the centrifuge. The radial mount has the advantage of using only one section of the pallet and the PCA does

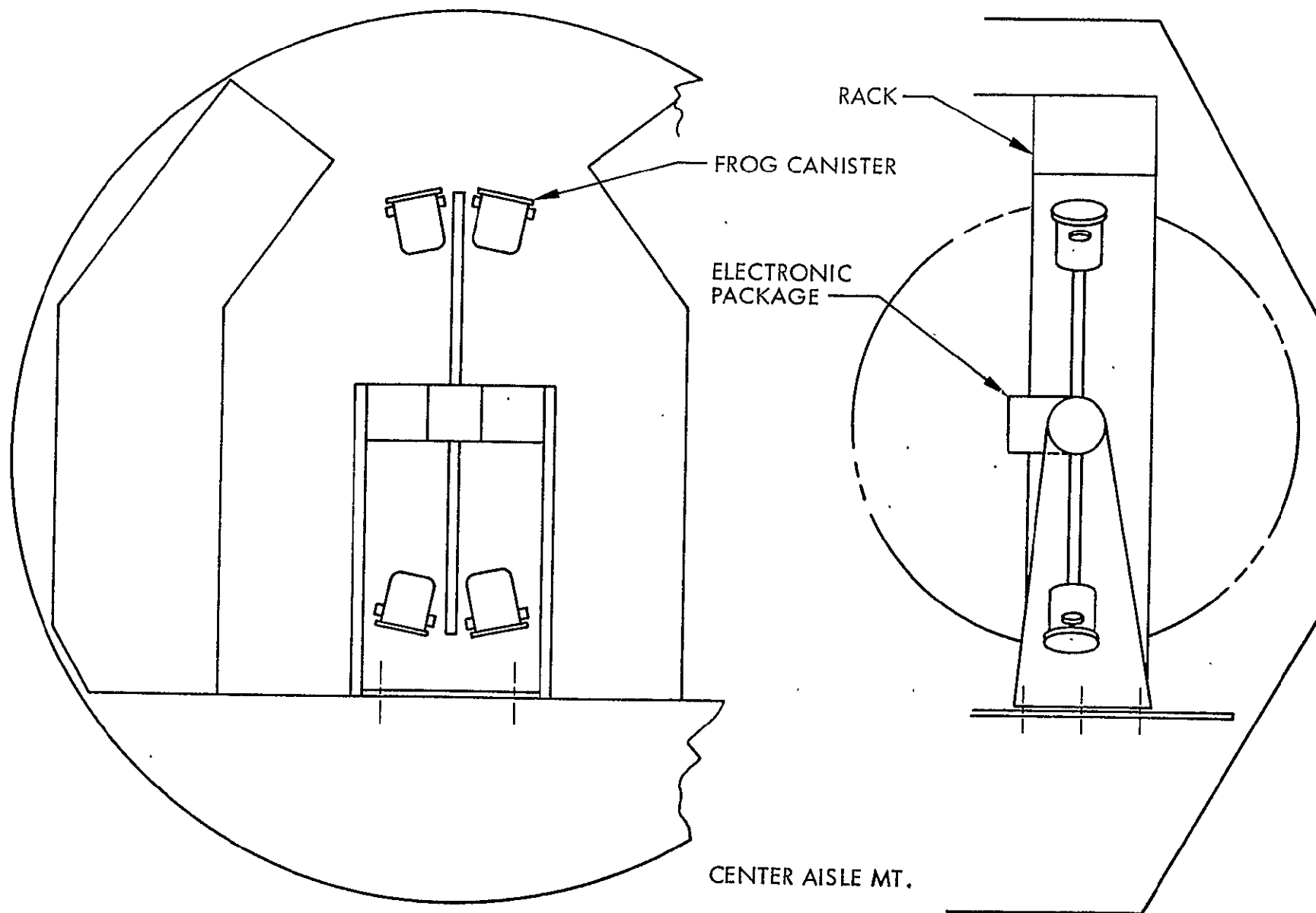


Figure 13 Spacelab Experiment - Center Aisle Mount

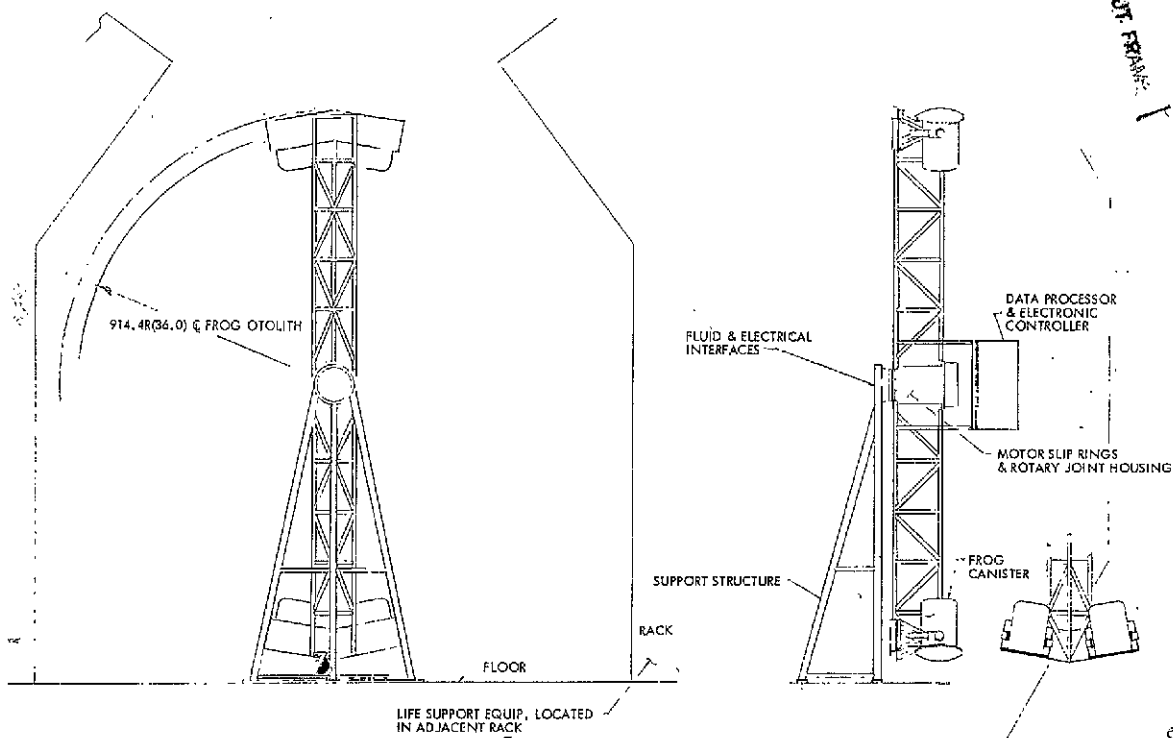


Figure 14 Spacelab Mounted VFR Experiment

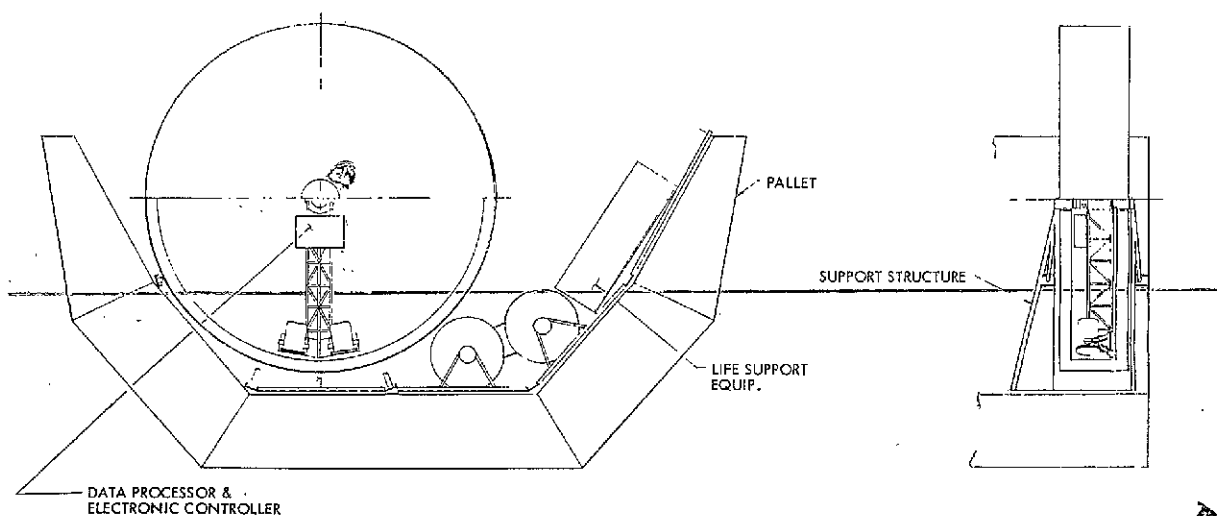


Figure 15 Pallet Mounted VFR Experiment

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EXPORT FROM 2

not connect to only one section, but is more suited to a payload that occupies an entire pallet. The centrifuge and centrifuge mounted equipment are identical to those used in the Spacelab module except that the data processor and electronic controller have been repackaged and relocated to provide room for support structure. A tubular support structure picks up the centrifuge center hub on each side of the centrifuge and supports the entire assembly from the pallet hardpoints. An outer shell around the centrifuge assembly provides thermal protection, but is not a pressure shell. The equipment located off the centrifuge is mounted to the pallet hardpoints directly. Life support, and data handling equipment and the electrical power distribution panel are packaged in an insulated box and attached to one of the pallet cold plates. The water tanks for bleed control of organics are insulated and attached by support structure to the pallet hardpoints.

VFR Mission Operations

A review of STS mission operations was conducted to support mission mode selection.

Prelaunch

Figure 16 shows the VFR experiment beginning at approximately T-400 hours as it is received and inspected at KSC. It enters the launch base level III integration at the Operations and Checkout building (O&C). Steps not directly pertinent or specific to the VFR experiment have been omitted in Figure 16 and in this discussion. The VFR experiment hardware is installed on the floor segment and racks - or pallet followed by validation of physical installation. Next these segments are installed into the O&C integration stand where experiment software is loaded and verified followed by the Integrated Systems Test (IST). After this the segments are moved to the module area and installed, beginning the level II integration. Here the subsystems (S/S) and VFR experiment are powered up and the functional interfaces between the experiment and subsystems are verified.

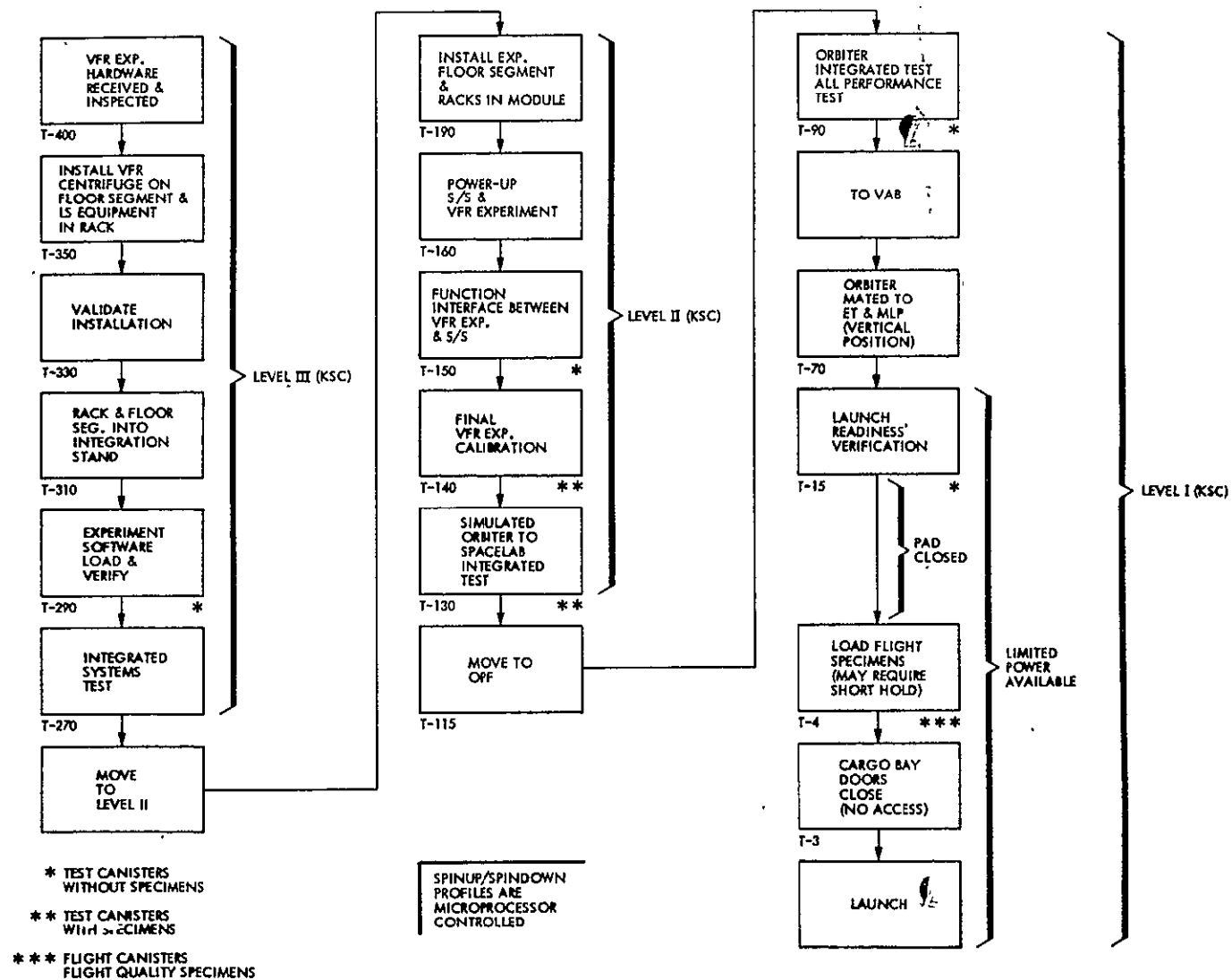


Figure 16 Mission Analysis - Preflight

The interface test and the IST can be accomplished without specimens in the canisters. All other aspects of the experiment will be fully operational. It should be noted that the centrifuge will be in the vertical position when the floor segments are horizontal, however functional testing should be acceptable in this orientation.

Final VFR experiment calibration is then performed. The next test simulates all orbiter functions and conducts a complete Spacelab integrated test.

The Spacelab is then moved to the Orbiter Processing Facility (OPF) where the cargo bay has been prepared for the specific Spacelab and pallet configuration. Level I integration now commences.

After mating to the orbiter and verifying all interfaces, including services, the ORBITER INTEGRATED TEST (OIT) is performed. The orbiter is then moved to the Vehicle Assembly Building (VAB) where it is mated to the internal tank and the mobile launch platform (MLP) along with the Solid Rocket Boosters (SRB). From this point on, the orbiter and spacelab are maintained in a vertical position.

After all work is completed in the VAB the vehicle is transported to the launch pad on the MLP.

Upon arrival at the pad the tower ingress/egress arm is mated to the orbit flight crew access hatch, and umbilicals and supports are extended and connected. The Payload Changeout Room (PCR) is then extended providing a clean environment to the Spacelab at the pad.

At approximately T-15 the Launch Readiness Verification (LRV) test is performed after which the pad is closed for hazardous fluid servicing which extends until approximately T-4. Power is limited during this period as the orbiter is progressively powered up in preparation for launch.

After hypergolic and other hazardous fluid servicing is completed (approximately T-4) the pad is opened and the specimens and other time critical items are loaded. A short hold is required to accomplish loading and procedural steps for VFR experiment verification. A preprogrammed spin profile is desirable at this time for prelaunch experiment data verification.

The access fixtures are removed and the cargo bay doors are closed at T-3, terminating access to the area. At T-2 a standby status is reached and resuming countdown the crew is ingressed. At approximately T-10 minutes the power is transferred from GSE to the vehicle. T-0 is lift-off.

Orbit

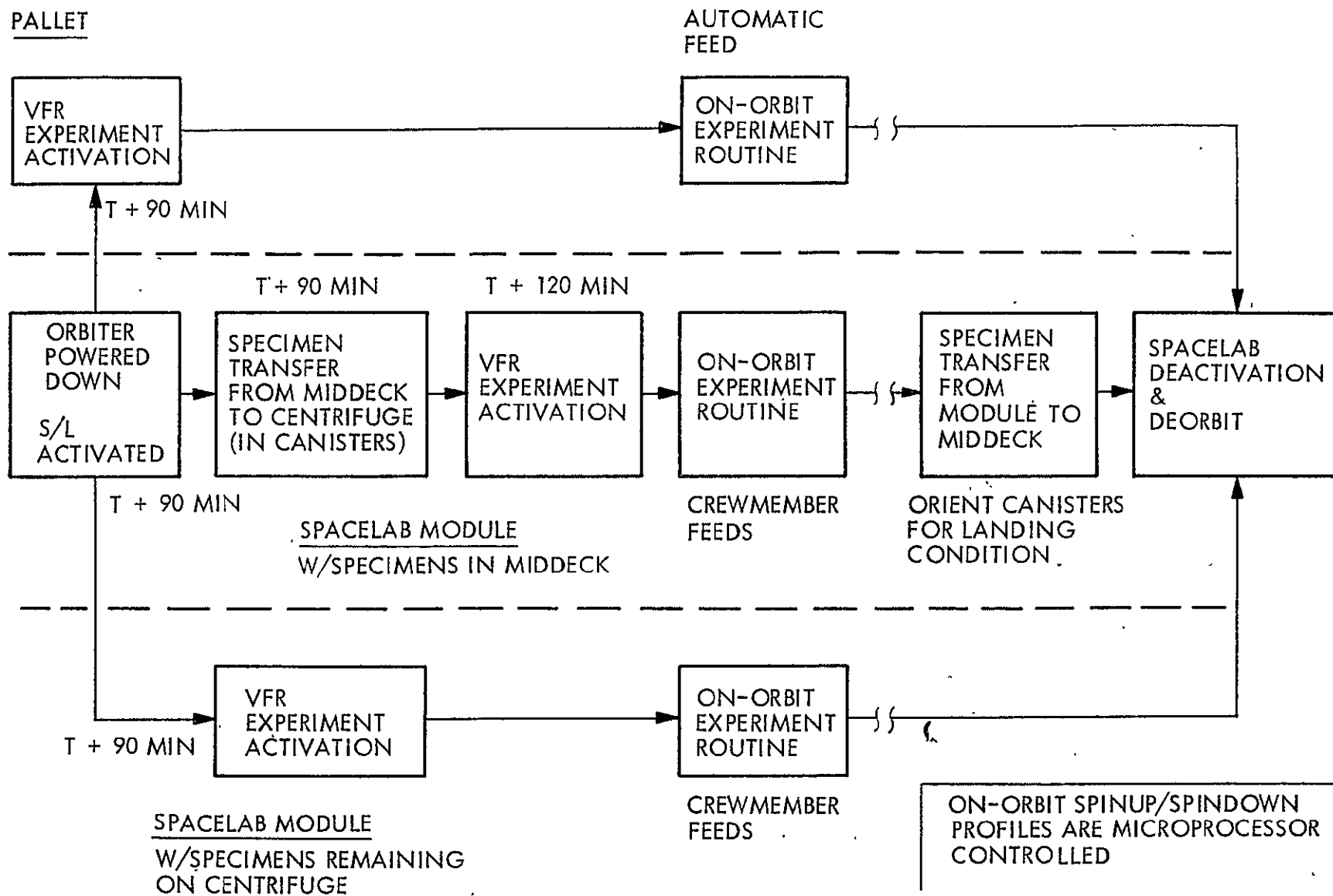


Figure 17 Mission Analysis - On Orbit

Power for experiment housekeeping will be limited during this period. The decision as to location of the specimens during launch and entry seems to hinge more on availability of power than any other factor or set of factors. The environment is equally severe on the mid-deck and in the module. Power is not that available on the mid-deck either during launch and entry.

Post Landing

Figure 18 presents the mission operations most significant to the VFR experiment during the post landing period. Within 15 minutes after touchdown GSE cooling and power will be connected to the vehicle. Access to the Spacelab module and specimens shall commence at approximately TD+30 min and extend up to TD+2 hours. The specimens may be removed during this period and transported to the ground centrifuge (MSOB) for post landing spin testing. After the specimen access period terminates, the orbiter is towed to the OPF for safing followed by opening of the cargo bay doors.

If the centrifuge were mounted on the pallet, access would probably not occur until approximately TD+15 hours. Therefore the capability of spinning the pallet mounted centrifuge is highly desirable.

Mission Mode Comparison

The Spacelab Module versus Pallet locations for the VFR experiment were compared on a subsystem, mission operations, and configurational basis. Advantages and disadvantages of each concept were generated and a recommendation as to the location of the equipment was made. Table 1 presents the advantages and disadvantages of the two mission modes.

Spacelab Module Mounted Experiment

The spacelab mount affords the opportunity for crew participation in the experiment. Although almost all of the experiment functions will be automated for both locations critical functions like feeding, administration of drugs, and correction of upsets can be performed by the crew. This is judged

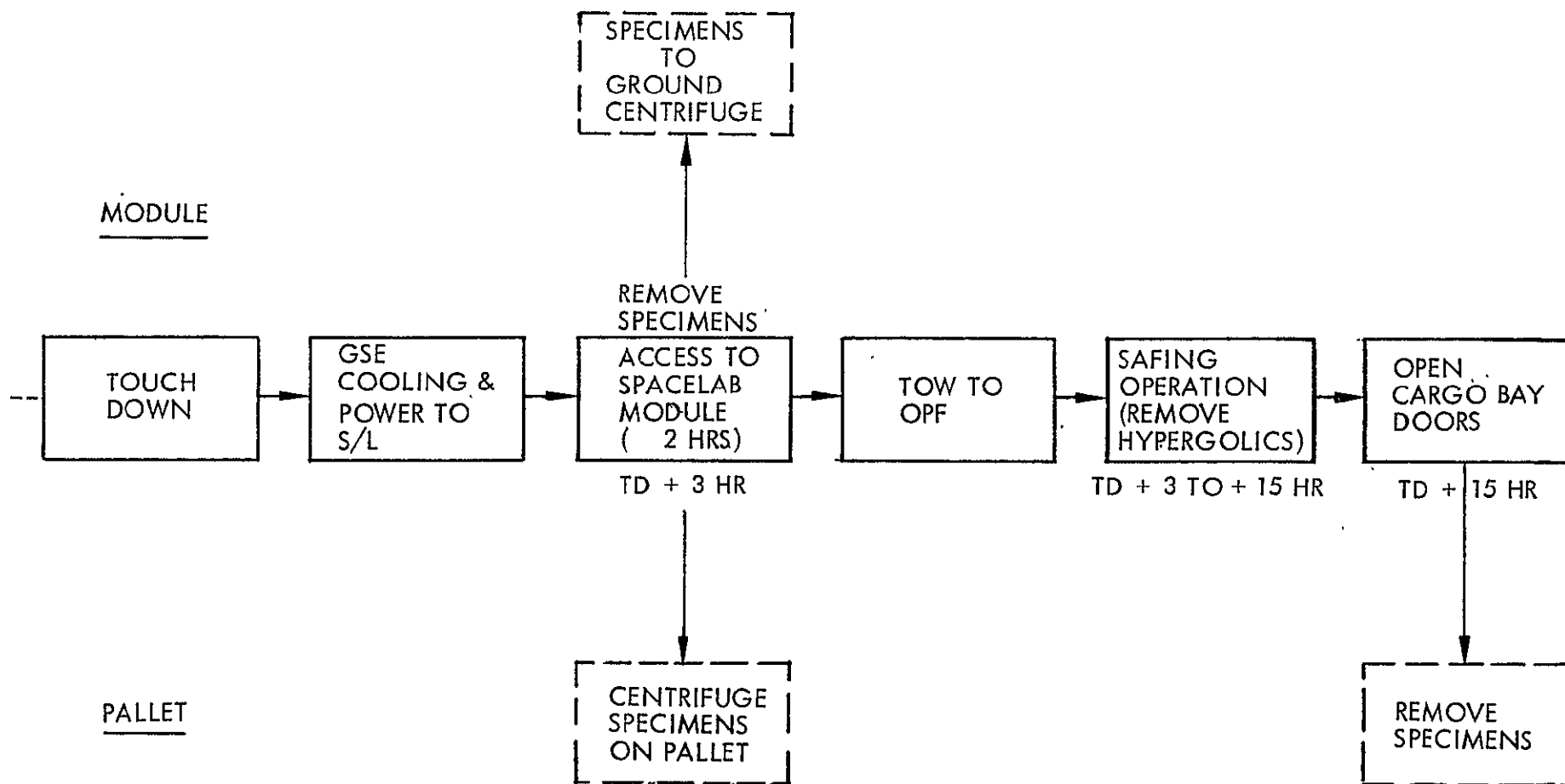


Figure 18 Mission Analysis - Post Landing

Table 1 Spacelab Versus Pallet-Mounted Experiment

	<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
SPACELAB MODULE	* ● CREW PARTICIPATION ● LESS MOUNTING STRUCTURE (30 LB) ● LOWER WEIGHT/POWER COOLING PENALTY (92 W VS 117 W) ● LOWER DISTURBING TORQUE (3×10^{-4} VS 5×10^{-4}) * ● LESS SPACE THERMAL PROTECTION (1 IN. VS. 3 IN.) * ● NORMAL PRESSURIZED ENVIRONMENT * ● LOWER COST (\$506,500) * ● EARLY ACCESS TO SPECIMENS AFTER TOUCHDOWN (T + 1 HR) ● LOWER VIBRATION/ACOUSTIC LEVELS TO FROG	● IMPACTS LOCATION OF SPACELAB EQUIPMENT * ● POTENTIAL SAFETY HAZARD
PALLET	● NO IMPACT ON SPACELAB AREA * ● NO PERSONNEL SAFETY HAZARD ● FULLY AUTOMATIC ● CAN FLY WITHOUT MODULE	* ● REQUIRES EQUIPMENT PROTECTION FOR UNPRESSURIZED ENVIRONMENT * ● REQUIRES TOTAL AUTOMATION ● NO SPECIMEN CHANGEOUT PAST T-4 HR * ● LATE ACCESS TO SPECIMENS AFTER TOUCHDOWN (T + 15 HR) * ● REQUIRES FROG FOOD DEVELOPMENT ● FROG WASHING REQUIRES SPECIAL COOLING PROVISIONS

to be a major advantage as indicated by a star next to this entry on Table 1. Less mounting structure is required for the Spacelab module mount because a thermal protective cover is not required, mounting of the water tanks and support equipment is made easier by use of an ESA rack and the centrifuge mount points are more readily accessible. Cooling penalties are also lower for the module mount, because circulating fluid temperatures are lower. Shuttle coolants go to the Spacelab module before going to the pallet. The differences in cooling penalties are small, however. The module mounted experiment is very close to the CG of the shuttle vehicle and therefore sees slightly lower "G" levels during attitude control corrections. The less severe thermal environment of the module mounted experiment during ascent, orbit and entry, reduces substantially the thermal protection required. The pallet system will require special thermal surfaces, superinsulation blankets and non-conductive isolators. This advantage is also considered to be a major one.

The Spacelab module mount also provides a normal pressurized atmosphere for the experiment equipment which means that more conventional electronic, electrical, and life support equipment can be used. This advantage offers major reductions in development effort. Although such special equipment is routinely used in many spacecraft applications it costs more to use. Lower total program costs are also associated with the module mount as a result of the less severe thermal and vacuum environment and the reduced development costs for specimen feeding. This is a major advantage. The module mount also provides access to the specimens immediately after touchdown. Early removal of the specimens means that the centrifuge mounting and position system can be simplified to avoid repositioning for a horizontal vehicle centrifuge spin cycle. This is also a major advantage of the module mounted experiment. Vibration and acoustic levels are also somewhat lower in the module during launch and entry.

The only significant disadvantages of the module mounted experiment are that it occupies space in the pressurized module that could be allocated to other

experiments that cannot be pallet mounted and that the rotating centrifuge does present a potential safety hazard to the crew. The centrifuge would be guarded, but an accident could happen.

Pallet Mounted Experiment

The Pallet mount does not impact the Spacelab module in anyway and does not require any significant amount of crew participation. It does not produce any personnel safety hazard. It offers the added advantage that with add-on capability the experiment could be made to be a free flying satellite.

The disadvantages of the pallet mount include the need for specially designed electronic, electrical, and life support components suitable for vacuum service and for greater ranges of temperature. The experiment must also be totally automated. These two disadvantages are identified as major. Access to the specimens prior to launch is precluded after T-4 for the pallet mounted experiment, but this should not be a major problem. Late access after touchdown is, however, a serious problem and requires that the experiment be capable of being positioned for a horizontal spinup or requires that no spinup be performed until after specimen removal at T+15 hours. The pallet mount also requires the development of a stable food capable of storage and automatic dispensing. These last two disadvantages being of major importance. The pallet mounted experiment also requires special frog washing provisions, because the pallet coolant temperatures are never low enough to support frog washing loads and the thermoelectric module penalty would be prohibitively high for this function. A water evaporative system was added for the pallet to meet this requirement, which was not needed for the module mounted experiment.

Recommended Mission Mode

Based on the relatively large number of advantages for the Spacelab Module mounted experiment, it was selected for the experiment location.

CONCEPTUAL DESIGN

The second task in the Phase B Preliminary Design Study was the conceptual design, which evolved several different approaches to meeting each subsystem, mission, and program requirement; compared the different approaches; and selected a preferred approach. Conceptual designs of several experiment options were prepared and cost estimates for each option were made. Specimen loading and unloading options and ground handling and support options were evolved and compared. Lockheed report LMSC-D058088 entitled "Conceptual Design Report" dated 17 May 1978 presents the results of this task of the study. A summary of that report is presented, herein. For added detail on the results of the conceptual design task the reader is referred to the more detailed report.

Mission Trade Studies

Mission operational studies conducted during the conceptual design task dealt with comparison of alternate specimen loading and retrieval systems, different means of providing ground support and transfer of the specimens during various mission phases, experiment personnel and ground support equipment requirements, and identification of STS on-board equipment requirements.

Mission Options

Sixteen different approaches to specimen handling during ground operations prelaunch, spacelab activation and deactivation and post landing were evolved and compared. Loading of the specimens into the Spacelab at T-6 and at T-70 hours and into the mid deck at T-6 and T-70 hours were studied. At this point in the study it was anticipated that the Spacelab III system would not be powered up during pad operation. Activation of S/L would occur at approximately T+12 hours but not earlier than T+6 hours. If the specimens were placed in the

Spacelab prior to activation, a self-contained power source would be required as part of the experiment hardware. The S/L will be deactivated at approximately TD-6.5 hours to begin thermal conditioning, again requiring a power source.

One of the sixteen mission modes compared during the study is presented by Figure 19 which covers specimen loading at T-6 into the Spacelab module and use of a ground support specimen transporter. Three flight type VFR experiment systems would be built, i.e., qualification, flight and spare units. The qualification unit would be sent to the PI's lab after refurbishment along with the 12 frog GSE transporter. The qualification unit could be used in specimen testing for baseline data acquisition and flight quality specimen selection. The GSE transporter provides a habitable environment for the flight and backup specimens at the PI's facility, during transit and at the launch site. Loading of the specimens into the Spacelab Module would be accomplished at approximately T-6 hours. The use of the PCR, PGHM, and S/L vertical access equipment would be required.

Indications at the time of conducting the conceptual design were that this experiment would be the only experiment requiring P/L Bay access on the PAD and that it may be the first to use the vertical access equipment. Additionally, the development and manufacturing costs of the access equipment may be chargeable to the VFR project, if such hardware were needed. A cost of approximately \$12,500 per hour for a hold will be charged against an experiment if it impacts the orbiter time lines and it is estimated such a loading would require approximately 6.5 hours.

A self-contained power source would be required to support the experiment from time of loading until Spacelab activation. It is possible to accomplish a centrifugation/data collection within 30 minutes after orbit injection with this mission mode. Tunnel access is required for early specimen retrieval, necessitating tunnel GSE as flyable hardware to support a man in a 1 g environment. An alternate would be to spin after touchdown utilizing a self contained system.

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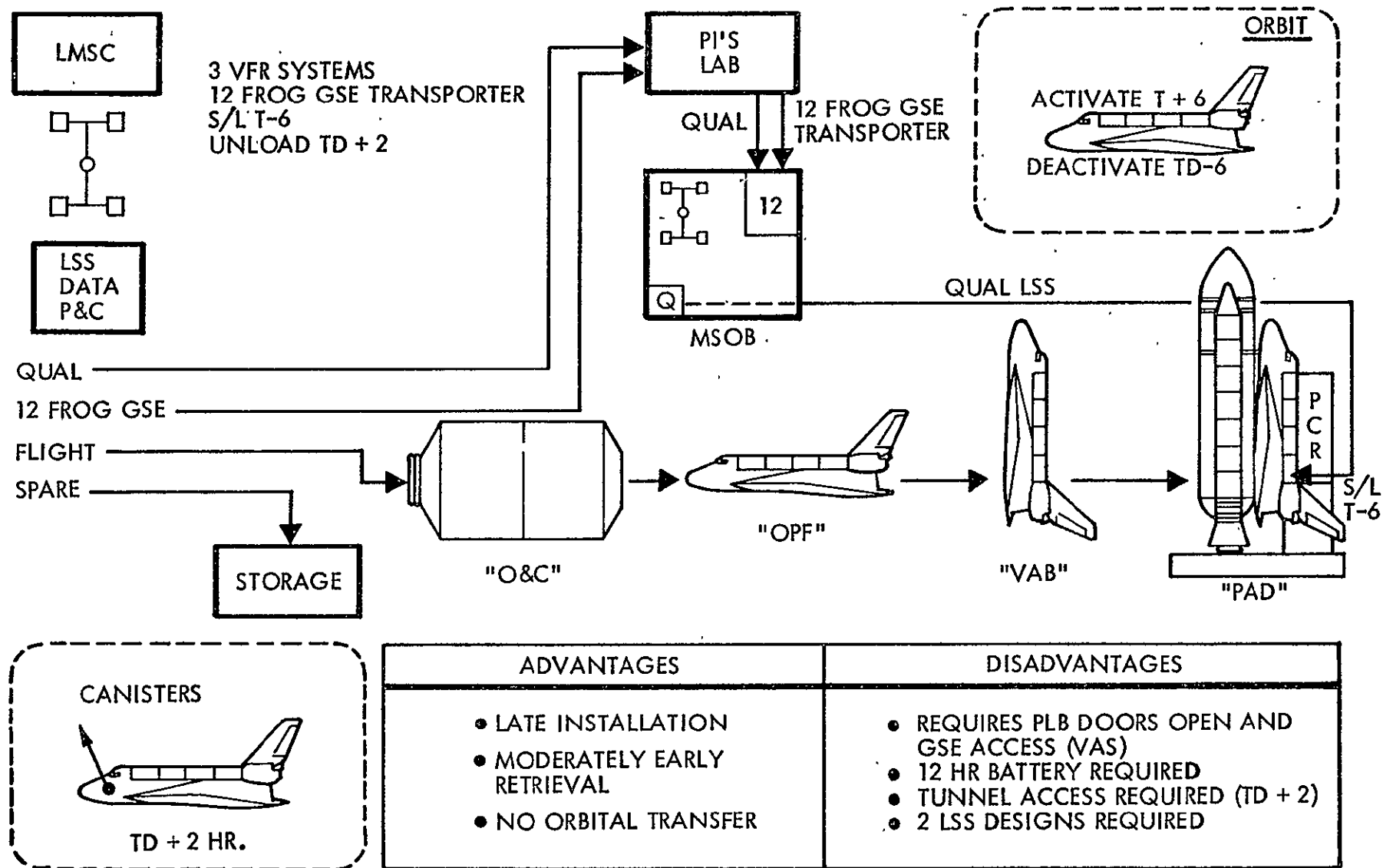


Figure 19 Spacelab Load at T-6 and GSE Transporter

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Comparison of Specimen Loading and Unloading Options

Table 2 compares the three most attractive specimen loading options showing the advantages of each approach. A check in the column indicates that a given concept offers the advantage listed. A star means that this factor is a major disadvantage. Table 3 presents a similar listing for specimen unloading after landing. Comparing the loading and unloading advantages and disadvantages of the three concepts shows serious disadvantages for all three concepts. Spacelab loading at T-6 hours provides the simplest flight hardware designs and best satisfies experiment requirements, but requires special access provisions for Spacelab just prior to launch. Mid-deck loading at T-6 hours provides access, but complicates hardware design and does not provide early on-orbit centrifugation. Spacelab loading at T-70 means that a large battery and automatic prelaunch program must be provided and that no data is available from T-70 until T+12 hours. A selection of preferred loading and unloading modes must await further study both at the experiment and STS mission level.

Transport Equipment Options

To provide specimen transport and holding during pre and post flight operations, three basic equipment designs were evolved. The first is a 12 frog Ground Transport presented by Figure 20 designed for ground use only to support 12 frogs during laboratory, pre-launch, and post landing preparations and testing. It would be relatively inexpensive to build, but does represent an additional piece of equipment, not needed by alternate concepts.

Figure 21 presents a four frog mid-deck transporter that provides three functions, i.e., a transporter for supporting specimen preparation, testing, and transfer; a mid-deck support system for prelaunch, launch, descent, and post landing; and a Spacelab on-orbit support system. One or two extra transporters could be built to support ground operations instead of building a special ground support unit. Included in the mid-deck transporter are life support, data recording, and electrical power.

Table 2 Specimen Loading Options

	MID DECK T-6	SPACELAB T-6	SPACELAB T-70
• DOES NOT REQUIRE NEW SHUTTLE GSE	✓	*	✓
• DOES NOT REQUIRE SPECIMEN TRANSFER ON-ORBIT		✓	✓
• SUPPORTS EARLY ON-ORBIT CENTRIFUGATION	*	✓	✓
• DOES NOT LEAVE SPECIMENS UNMONITORED FOR LONG PERIODS	✓	✓	*
• DOES NOT REQUIRE MID DECK SYSTEM	*	✓	✓
• DOES NOT REQUIRE SELF CONTAINED FIRE DETECTION & SUPPRESSION EQUIPMENT	✓		
• DOES NOT REQUIRE HOLD AT PAD	✓		✓
• DOES NOT INCREASE LSS & TAPE RECORDER	✓	✓	
• SIMPLIFIES CENTRIFUGE DESIGN	✓	✓	
• BATTERY REQUIRED (LB)	0	54	415
*MOST IMPORTANT PROBLEMS			

Table 3 Specimen Unloading Options

	MID DECK TD + 1	SPACELAB TD + 2	SPACELAB TD + 15
● DOES NOT REQUIRE NEW SHUTTLE GSE	✓	*	✓
● DOES NOT REQUIRE SPECIMEN TRANSFER On-ORBIT		✓	✓
● DOES NOT LEAVE SPECIMENS UNMONITORED FOR LONG PERIODS	✓	✓	*
● DOES NOT REQUIRE MID-DECK SYSTEM	*	✓	✓
● DOES NOT REQUIRE SELF CONTAINED FIRE DETECTION & SUPPRESSION EQUIPMENT	✓		
● SIMPLIFIES CENTRIFUGE DESIGN	✓	✓	
● DOES NOT REQUIRE AUTOMATIC POST LANDING CENTRIFUGE CONTROL	✓	✓	
● DOES NOT COMPLICATE LSS DESIGN	✓	✓	*
*MOST IMPORTANT PROBLEMS			

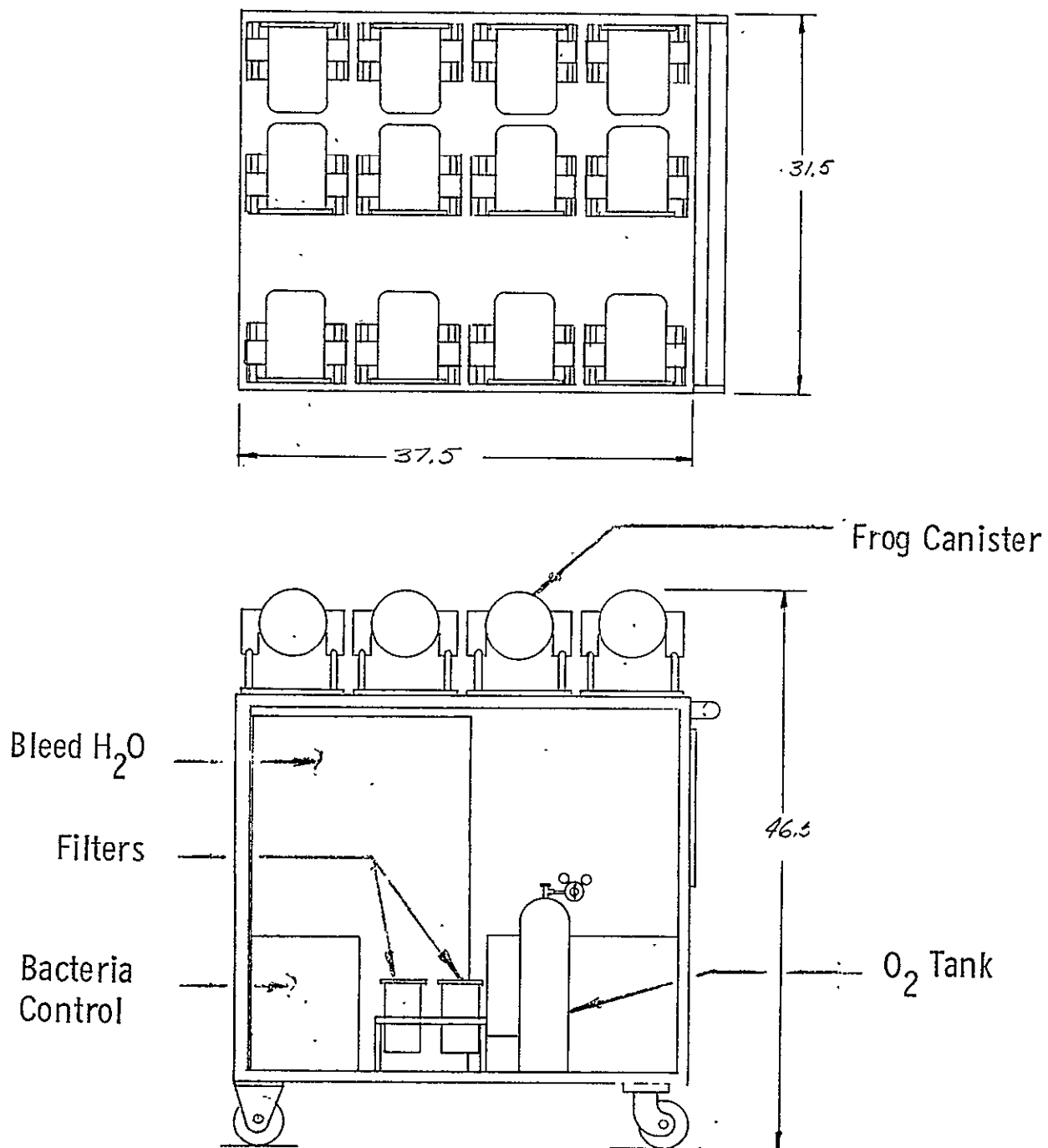
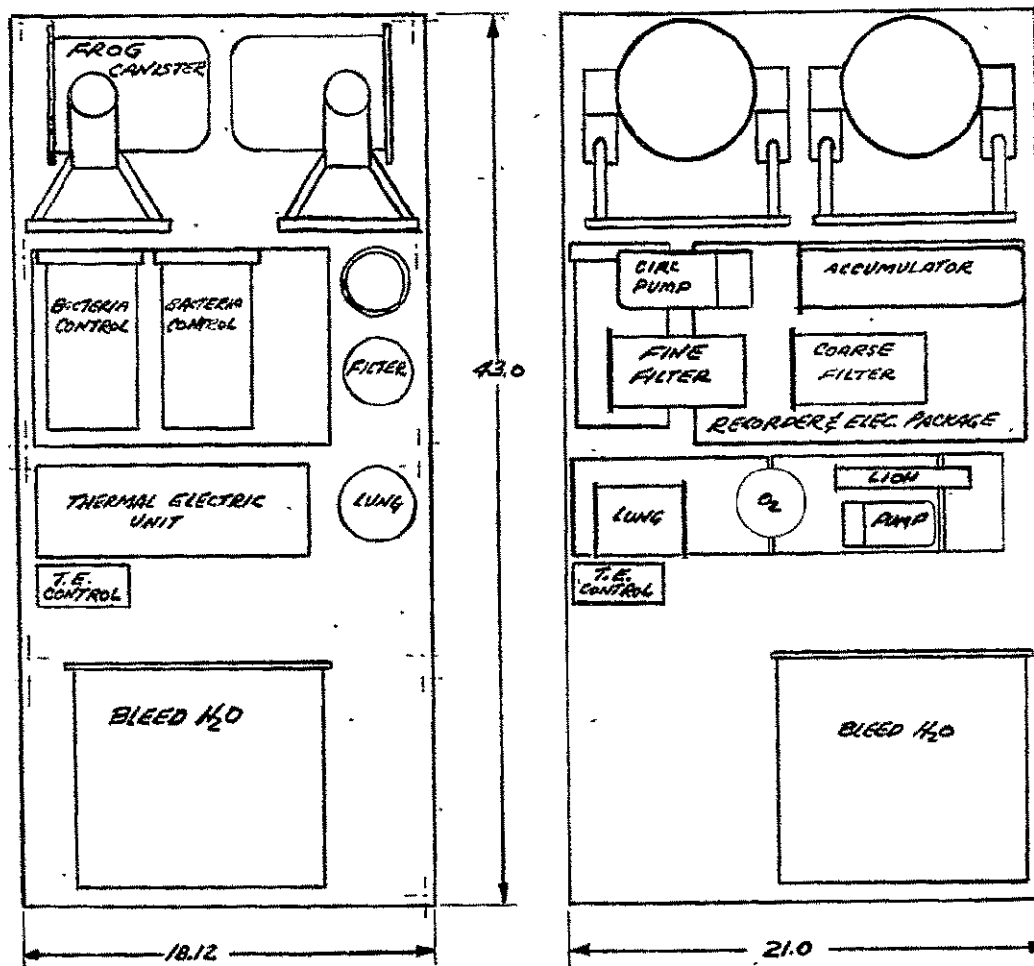


Figure 20 12 Frog Ground Transporter



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Figure 21 4 Frog Mid Deck Transporter

Another concept utilizes flight, qual, and spare systems that are designed to support 12 frogs for 4 days during ground operations and to support four frogs for 8 days with a 50 percent reserve for flight operations. The weight, power, and cost penalties are small for this approach. Included in the package are life support, data recording and electrical power.

Table 4 compares the three ground handling concepts with respect to operational flexibility and program cost. The 12 frog ground support transporter was selected, because it provides the greatest operational flexibility.

Life Support System Trade Studies

The life support system for the VFR experiment provides the following functions:

- o Urea removal
- o Oxygen supply
- o Carbon dioxide removal
- o Solids removal
- o Frog washing
- o Bacterial control
- o Thermal control
- o Specimen Feeding

Trade studies were conducted in each of these areas to define a preferred approach. System schematics were prepared and a list of advantages and disadvantages of each approach were reviewed to make a final selection. A summary of each trade is presented in this report.

Urea Control

Urease, reverse osmosis, ozonation, hypochlorination, and a bleed water system were compared for urea removal. Initially a maximum allowable urea concentration of 4 ppm was specified. The weight and volume penalties for a bleed water system to maintain a urea concentration of 4 ppm were prohibitive. Figure 22 plots bleed water weight (without tankage) vs urea concentration showing

TABLE 4 SPECIMEN GROUND HANDLING

	12 FROG GSE	ONE EXTRA FLT TRANS	TWO EXTRA FLT TRANS	12 FROG FLT SYSTEM
● NO NEW SYSTEM DESIGN		✓	✓	✓
● PROVIDES GROUND SYSTEM BACKUP	✓			
● DOES NOT REQUIRE CRITICAL GROUND OPS TIME PHASING	✓		✓	✓
● PROVIDES FLEXIBILITY FOR SPECIMEN TRANSFER TO PAD	✓	✓	✓	
● ADDED PROGRAM COST	\$220 K	\$180 K	\$360 K	\$75 K

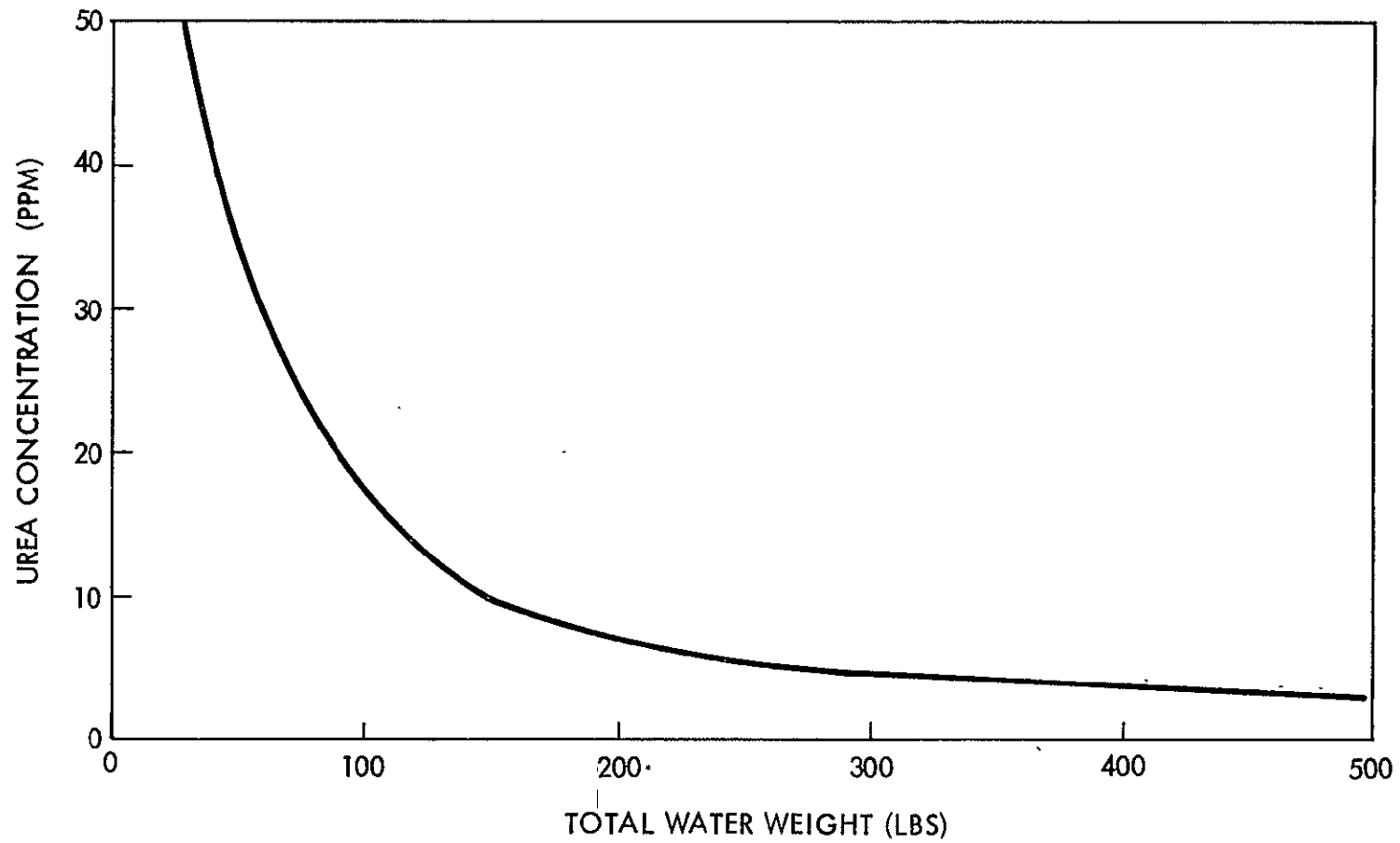


Figure 22 Fresh Water Required vs Urea Concentration

that approximately 379 pounds of water are required for 4 ppm urea for a mission duration of 8 days plus a 50 percent margin. The alternate approaches to urea control are not very attractive possibilities. Urease requires further development to prove its ability to control urea for this application. Reverse osmosis requires development and complicates the system design as a result of ion imbalance and high pressures. Ozonation may not effectively control urea and requires complex generation and dispersion equipment as well as high power consumption. Hypochlorination offers the best alternative design but does require addition of makeup salts for ion balance control and removal of residual hypochlorite upstream of the frog canisters.

As a result of the complexities of the alternate designs and the high penalty of the bleed system, a review of the allowable urea concentration was made and it was decided that a maximum of 50 ppm could be allowed. The bleed water requirements are reduced to approximately 30 pounds, so the bleed water system approach was selected.

Oxygen Supply

Gaseous, liquid, and chemical oxygen sources were considered as candidate means of supplying oxygen to the system. Considering the ease of storage, handling and control, gaseous oxygen was a clear choice for the VFR experiment. The weight and volume penalties are very small.

Oxygen Transfer to Water

The trade study on concepts for transferring oxygen into the water circulation loop considered various chemical contactors, a gas contactor and the use of a membrane lung.

Chemical contactors that were considered were solid potassium superoxide (KO_2) and aqueous solutions of hydrogen peroxide (H_2O_2) and sodium hypochlorite (NaOCl). KO_2 was discounted because of foreseeable difficulties in solids handling and control of the decomposition rate. H_2O_2 and NaOCl as liquid sources would be easy to inject, but would require PO_2 sensor control of feed

rate and a separate method of CO₂ removal. NaOCl would serve the multiple functions of oxygen transfer and urea and bacteria control, but would require ion-balance control.

In the gas contactor concept, gaseous oxygen would be injected via a static mixer and would require an active gas/liquid separator downstream of the contactor. This concept also has the disadvantages of (1) the possibility of gas bubbles entering the canisters and (2) saturating the recycle oxygen with water vapor which could degrade the LiOH bed performance by causing clumping.

The membrane lung concept is favored over the other concepts considered because it has been proven in long term testing and it provides the easiest means of controlling oxygen feed. Although the membrane is a resistance to gas transfer, the effect is small and easily overcome by controlling the differential pressure.

Carbon Dioxide Removal

The use of a membrane lung, a gas contactor, ion exchange and chemical neutralization were considered for carbon dioxide removal.

Chemical neutralization would consist of pH adjustment to the basic side to "fix" the dissolved CO₂ as carbonate and bicarbonate with the disadvantage the excessive ion buildup would occur during the mission. The use of an ion exchange resin to remove the excess ions would impose a severe weight penalty ($\approx 300\%$) and would require salt makeup to control the ion balance.

The membrane lung was selected over a gas contactor because it has been proven successful in long term testing and is a passive device compared to the active gas/liquid separator required for the gas contactor approach.

Solids Removal

The solids generated by the frog are primarily skin, fecal matter and mucus. Solids removal concepts compared during the trade study were filtration, centrifugation, and vortex generation. Filtration is the simplest and most

reliable methods for solids removal. Laboratory tests have proven that a two stage design utilizing 20 mesh coarse and 40 μ fine filters will adequately provide for solids removal for the 8 day mission with filter areas of 25 in² per frog per day. Based on the simplicity of the changable cartridge filtration method it was selected over the other concepts.

It was observed during laboratory testing that centrifuging was a very effective way of removing solids from the frog water. Under laboratory centrifugation most of the solids including the frog skin was compacted into a very small volume but a centrifuge produces power, weight, and reliability penalties not inherent to a filtration system. The g force required to achieve effective solids removal must be established by test, before a final centrifuge design can be established. A five "g" force was used in this trade off study for system sizing and power estimation. If major difficulties were encountered with the filtration method, the centrifuge design should be considered in more detail, including the combination of a centrifuge with a fine filter to increase small particle removal efficiency. Combining the centrifuge with the frog water circulating pump into a single unit to minimize power and weight penalties and increase system reliability should also be considered.

A vortex generator that channels the frog water flow into a circular motion to produce a 5 g force was considered for solids removal. Since the stationary piping generates the circular motion, the circulating pump must provide the power required to achieve the 5 g force field. The Vortex generator should be more reliable than the centrifuge approach. Equipment design development and testing would be required to produce an acceptable design.

Frog Washing

Based on analytical design and laboratory testing the following four frog washing concepts were compared:

- o Single rack mounted water pump capable of delivering required velocities to all frog canisters simultaneously through the circulating fluid plumbing.

- o Single centrifuge mounted pump capable of washing all frogs simultaneously.
- o Small water pumps individually mounted on each canister
- o Propellers mounted inside each frog canister driven by electric motors outside.

During the conceptual design study the use of individually mounted propellers was selected over the other concepts, because it required less power than the other concepts and produced better water velocities over the entire frogs body. Later in the study, when the requirement for positioning of the frogs in all three axes to any position was added the selection was changed. The added complexity of a three axes canister positioning system made it difficult to mount a motor and propeller on each canister. Location of two control frogs to the rack mount also affected the decision, because they too had to be washed. The end result was a decision to use a rack mounted water pump to wash all six frogs using as large as possible ($\frac{1}{2}$ " od) fluid lines in order to minimize pressure drop and power consumption.

Bacterial Growth Control

The nine concepts listed below for bacterial growth control were studied.

- o Acidification - Adjustment of the frog solution periodically to a pH of between 4 and 4.5. Acid has been used in spacecraft urine recovery systems to prevent bacterial growth and its ability to control bacteria in the frog solution has been preliminarily demonstrated.
- o Iodination - Generation of Iodine by an electro chemical cell using iodine crystals to control I_2 concentrations in the circulating frog solution between 3 and 5 ppm. This approach has been used in spacecraft drinking water systems, but complicates the system, and the effect on the frogs is unknown.
- o Hypochlorite - A programmed addition of hypochlorite to control bacteria growth with removal of residual hypochlorite upstream of the frog canisters. This concept complicates the system and may not be as effective as desired.

- o Organic Bactericides - Stored chemical pumped into the flow stream. The effectiveness of any bactericide that will not harm the specimens is in question.
- o Iodine Resin - A resin bed located in the flow stream that kills bacteria in contact with the resin. This concept provides only limited bacteria control in the resin bed and does not prevent growth in the rest of the system.
- o Ozonation - An ozone generator that provides a constant supply of low concentration ozonated water in the system excluding the frog canisters. The high power consumption, gas/liquid interface problems and instability of ozone eliminated this concept.
- o Silver Ions - An electrochemical cell or fixed AgBr bed located in the flow stream designed to provide 0.5 to 1 ppm of Silver Ion in the frog solution. The unknown effect on the frogs, and low effectiveness of this approach precluded its selection.
- o Ultraviolet Light - A UV generator in the flow stream. The difficulty of getting the light in contact with the bacteria due to high transmission losses eliminated this approach.
- o Heat - Hold the entire system excluding frog canisters at 160°F using a regenerative heat exchanger to conserve energy. Power consumption of over 900 watts is prohibitive for this approach.

A comparison of these approaches was in progress when information was received that the effectiveness of the acid addition had been confirmed by tests run at the University of Pittsburgh facility. These preliminary test results led to the selection of the acidification method for bacterial control. Effective control of bacteria for long periods of time had been demonstrated by sterilization prior to the insertion of the frogs, adjustment of the pH to between 4 and 4.5 for several hours, followed by a pH shift to between 6 and 7. This concept provided a simple approach to bacteria control for the VFR program.

Thermal Control

The cooling available from the orbiter and Spacelab cannot provide direct thermal control for the VFR experiment. Coolant temperatures are greater

than 62°F under many orbital heat load conditions and during ascent and descent. Active thermal control concepts compared during the study included Thermoelectric, evaporator, and vapor cycle. Vapor cycle systems were eliminated because they require extensive development work to provide a zero gravity unit of the proper size for the VFR experiment. In addition vapor cycle systems produce noise, are more complex and present a potential contaminant problem to the spacecraft atmosphere.

Table 5 presents a comparison of five thermal control concepts. The first concept used a thermoelectric unit picking up heat from a liquid heat exchanger located in the frog water circulation loop and rejecting the heat to the cabin air through an air exchanger/blower assembly. The second concept was identical to the first except that the frog solution was passed through the Spacelab experiment heat exchanger prior to entering the thermoelectric (TE) unit. Concept 3 rejected all experiment heat through the TE to the Spacelab liquid coolant system. Concept 4 utilized an evaporative heat exchanger in series with the Spacelab experiment heat exchanger. Stored water was evaporated over-board whenever the experiment heat exchanger could not meet temperature requirements. The fifth concept utilized an evaporator for all experiment cooling needs.

A comparison of the five concepts led to the selection of concept 2, because it was a reasonable compromise between vehicle integration problems and system weight and power requirements. Concepts 4 and 5 required ground cooling connections not currently provided by Shuttle for periods when Spacelab is deactivated and required an evaporator vent not currently provided. Concept 3 required continuous operation of the Spacelab cooling system which is not currently planned for all ground operations and for ascent and descent. Concept one minimizes vehicle interfaces, but requires more power than concept two. The complexity of integrating with the experiment heat exchanger, reductions in TE unit power requirements and the need to electrically isolate the frog solutions from Spacelab grounds led to a final selection of concept one later in the study during the preliminary design task.

Table 5 Thermal Control Comparison

EXPERIMENT COOLING	POWER CONSUMPTION (WATTS)			SIGNIFICANT WEIGHT EFFECTS KG (LB)		CONSIDERATIONS
	AVE	PEAK	A/D			
1) TE/CABIN AID	152	382	230	NONE	o	MINIMUM INTERFACE
					o	HIGH POWER
					o	CONTINUOUS OPERATION
2) TE/CABIN AIR/ EXP H-X	92	247	230	NONE	o	LOWER POWER
					o	DESIGN FLEXIBILITY
					o	INTERMITTANT OPERATION
3) TE/EXP H-X (SEPARATE LOOP)	121	330	149	NONE	o	NO CABIN HEAT
					o	CONTINUOUS OPERATION
					o	CONTINUOUS FLUID CIRCULATION
4) EVAPORATOR/ EXP H-X	32	247	32	55 (120)	o	LOW POWER
					o	GROUND COOLING CONNECTIONS
					o	HIGH WEIGHT
5) EVAPORATOR	32	247	32	65 (143)	o	LOW POWER
					o	GROUND COOLING CONNECTIONS
					o	HIGH WEIGHT

Data System Trade Studies

Data system trades investigated the state of the art of accelerometers to meet the requirements for a frogs head mounted accelerometer, compared various analog and digital systems, compared Spacelab and experiment provided tape recorders, and established interface methods.

Accelerometer Design Study

At this point in the study it was desired to mount an accelerometer on the frogs' head that provided the following capabilities:

- o Volume less than 1 cc
- o Frequency response DC to 600 Hz
- o Weight less than 10 grams
- o Resolution 10^{-3} g
- o Full Scale Range ± 1 g

To meet these requirements, the technology of servo, piezoelectric and piezoresistive accelerometers were reviewed. It was concluded that only piezoresistive could possibly meet the requirements and then only if noise can carefully be controlled and thermal compensation is included. Reduction in required frequency response was recognized as an important factor in reducing accelerometer problems, so 250 Hz was selected for the preliminary design task with concurrence of the principal investigator.

Table 6 presents four accelerometer concepts using different accelerometers on the frogs head, canisters, centrifuge base and ground transporter. These concepts provide less development effort and risk, but also provide less direct or usable data as the concept number increases. Concept 2 was selected because it meets experiment requirements with a reasonable amount of development risk and expense. Concept one was eliminated as requiring too much development and concepts 3 and 4 compromised experiment requirements to a greater degree than was required by the available technology.

Table 6 Accelerometer Concepts

CONCEPT	FROG HEADS	CANISTERS	TRANSPORTER	CENTR. BASE	CENTR. AND CANISTER FDBK
1	$\pm 4g, 10^{-3}g,$ 0 to 600 Hz	Same On One Only	None	None	✓
2	$\pm 1g, 10^{-3}g,$ 0 to 600 Hz	Same On One Only	$\pm 4g, .04g,$ 0 to 600 Hz	$\pm 4g, .04g,$ 0 to 600 Hz	✓
3	$\pm 1g, 10^{-2}g,$ 0 to 300 Hz	$\pm 4g, 10^{-3}g,$ 0 to 600 Hz	None	None	✓
4	None	$\pm 4g, 10^{-3}g,$ 0 to 600 Hz	None	None	✓

Analog vs Digital Data Comparison

Six analog, digital and hybrid systems were compared for data collection and transmission.

<u>Concept</u>	<u>Data System</u>	<u>Recorder</u>
1	All Analog	Payload
2	All Analog	Experiment
3	Analog/Digital	Payload
4	Analog/Digital	Experiment
5	Digital	Payload
6	Digital	Experiment

For each basic type of data system, the use of the Spacelab payload recorder and a special experiment recorder was considered. Figure 23 presents the selected concept using a hybrid system and an experiment provided recorder. The experiment requirements for data recording during ascent cannot be met with concepts 1, 3, and 5 because the Spacelab data system including the payload recorder is deactivated at this time. A complete analog system, Concept 2, was not selected because of high GSE costs, low accuracy, and incompatibility with automatic checkout equipment. Concept 6 did not meet experimenter requirements for backup analog recording of otolith data during flight. The analog/digital system with experiment recorder best met experiment requirements with little increase in cost.

The main operational characteristics of the selected data system are: The PCM multiplexer will have three bit rate/output format modes. The high bit rate mode will multiplex and encode all data for output to the HRM/HD RR. This will be the primary mode of experiment data acquisition. The medium bit rate mode will be used in conjunction with the analog FM/FM multiplex for recording data during ascent, re-entry and periodically during experiment operations. This data is validation data and may or may not be down linked. The low bit rate mode is to accommodate continuous acceleration data from one specimen. During times when experiment data is not required the system will be in the low bit rate mode and will output the acceleration data to the down link via the HRM/HD RR. Data from the LSS and other selected system status monitors

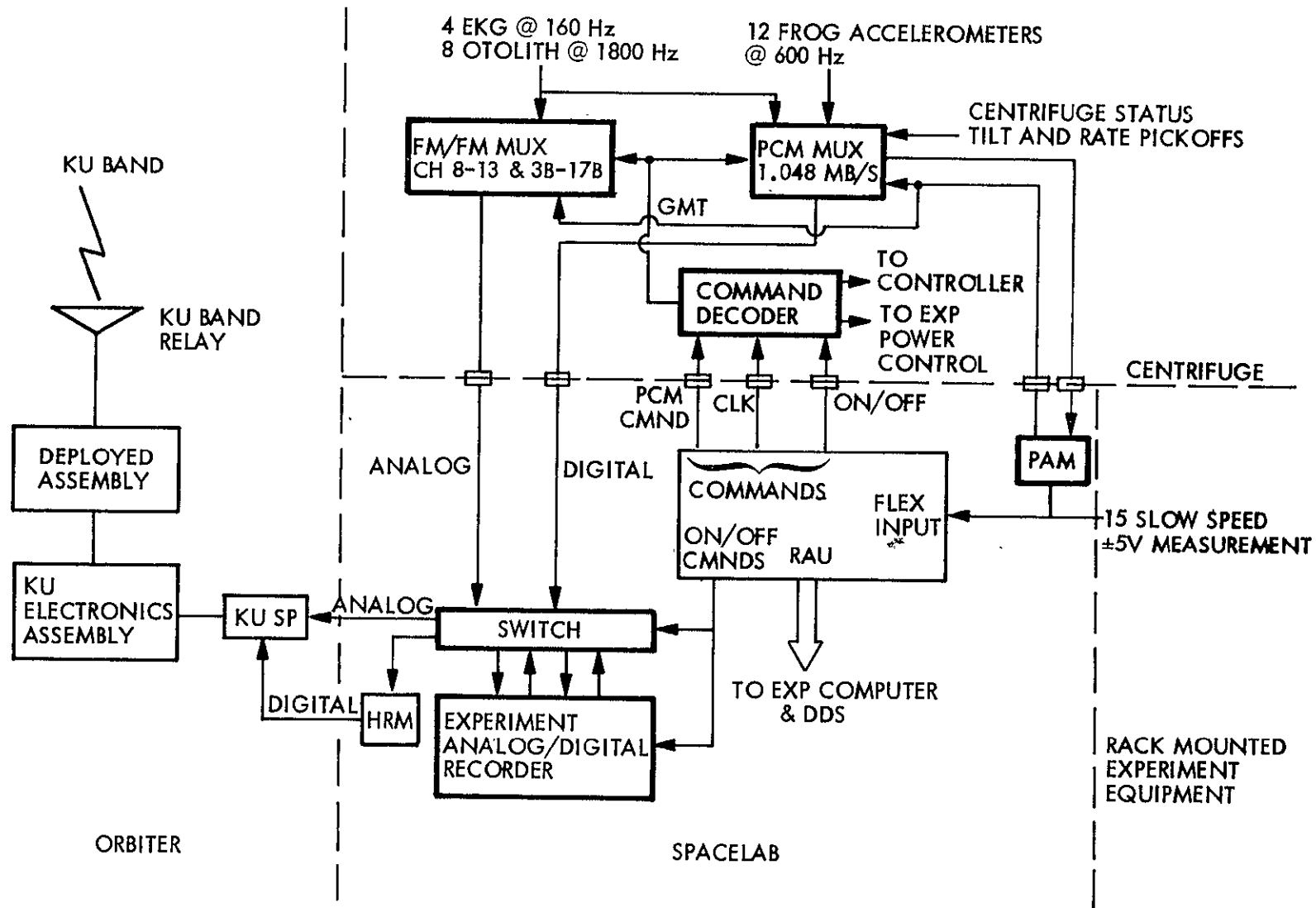


Figure 23 Concept 4 Analog/Digital Data System Experiment Recorder

will be redundantly monitored via RAU so that experiment health assessment can be made by the experiment specialist via the DDS or by experiment flight controllers via the engineering data down link.

Experiment Design Trade Studies

Design trade studies conducted during the conceptual design included

- o A study of equipment mounted on vs off the centrifuge
- o The need for and design of torque compensation devices
- o Frog container configuration
- o Centrifuge beam design
- o Centrifuge configuration
- o Centrifuge mounting
- o Materials of construction

Equipment On vs Off Centrifuge

A study of the experiment hardware led to the following conclusions with respect to equipment location. Placing the data system signal conditioners, multiplexer, VCO assembly and power supplies on the centrifuge offers the advantages of reduced number of slip-rings and reduced noise problems. Location of the centrifuge controller and micro computer on the centrifuge also minimizes the number of slip rings and facilitates checkout of the system as a unit. The weight and dynamic balancing problems of this equipment being placed on the centrifuge are small.

The life support system is best located off the centrifuge, because of its relatively large mass, changes in mass distribution due to shifts in consumables, vibration caused by equipment operation, reduced number of slip rings, and easier packaging and access. The need for rotating fluid joints and longer fluid lines are the only disadvantages. Fluid joints may be required even if the life support system were mounted on the centrifuge depending on the interface with the cooling system.

Torque Compensation

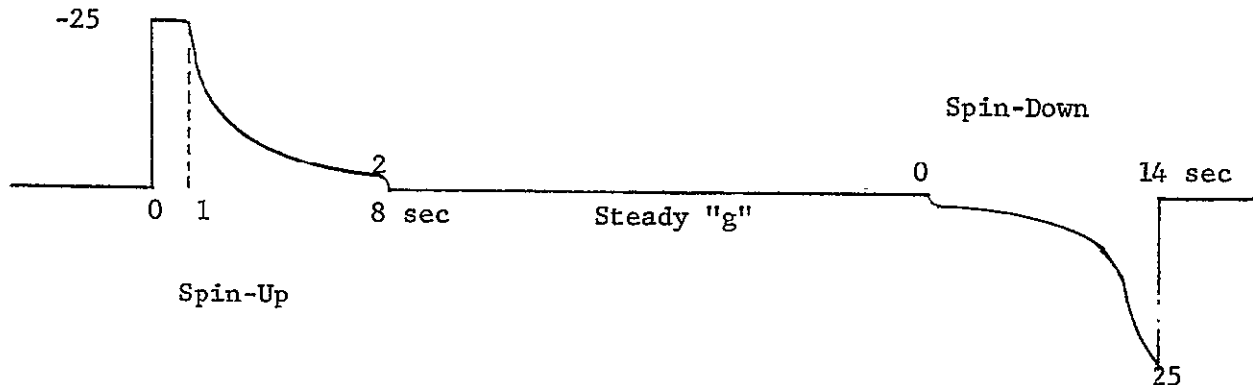
The need for torque compensation was studied to establish design requirements. The response of the vehicle to both spin cycle and steady "g" operation while the vehicle is in the active attitude control mode and the gravity stabilized mode was calculated. In the active attitude control mode the vehicle is controlled by the vernier jets to maintain a selected position in orbit. Centrifuge spin-up torque requirements were estimated at 10 ft-lbs early in the study. To study the response of the vehicle to a spin cycle a simplified torque vs time profile was input into a Shuttle dynamic model simulator program developed by the Lockheed Electronics Company in Houston, Texas. A torque of 10 ft-lbs was applied for the 8 second spinup, 2 ft-lbs was applied for the 60 second constant speed drive, and a -6 ft-lbs was used for the 14 second spin down. The vehicle and attitude control system response to the spin cycle are summarized below:

Maximum vehicle roll rate	= 0.01 deg/sec
Maximum vehicle attitude change	= 0.1 deg
Vehicle Response to centrifuge torque	= 1×10^{-6} g
Vehicle Response to attitude control jets	= 2×10^{-4} g
Total fuel used per cycle	= 0.334 lb
Total cycles per 8 day mission	= 70
Total fuel usage in 8 days	= 24 lbs

The response to a steady "g" profile was very similar to a spin cycle. The greatest amount of centrifuge torque occurs at a speed of zero. To accelerate from 0.3 "g" of a spin cycle to a 1.0 steady "g" requires very low torques (less than 2 ft-lbs). Also the vehicle response to centrifuge torques is very low. The vernier thrusters create the higher vehicle "g" forces. Additional fuel is not required by a long duration constant "g" run because constant "g" running torques do not act on the vehicle, but are compensated for by bearing friction and windage.

Addition of increased capability to the centrifuge and canister positioning design following the conceptual design increased centrifuge weight and torque

requirements greatly. The following revised torque requirements resulted from the preliminary design task.



Examination of these revised torque requirements resulted in the conclusion that the vehicle response would not be adversely affected. The vehicle response was still controlled by vernier firing not centrifuge torques. The total impulse to the vehicle was slightly less with the new profile, because the area under the new curve was 72 ft-lb-sec compared to 80 ft-lb-sec for the old curve. Therefore the number and length of vernier firings would be about the same with the revised torque profile.

With respect to disturbances to the gravity stabilized mode both spin cycle and spinup for steady "g" were imposed on a stabilized vehicle and resultant acceleration forces were calculated with the following results

About Vehicle Axis	Accelerations (g) at Spacelab Location x = 1124, y = 0, z = 400	
	Spin Cycle	Spinup for Steady "G"
x	4.5×10^{-8} to 3.5×10^{-8}	4.5×10^{-8} to 3.5×10^{-8}
y	-2×10^{-7} to 4.3×10^{-7}	-2×10^{-7} to 4.3×10^{-7}
z	No Change	No Change

As with the active attitude control mode there was no change between a spin cycle and a steady "g" spin-up, because the most severe torque requirements exist in the first few seconds of startup from zero which is common for both cases.

In parallel with attitude control system studies, consideration was given to torque compensation methods. Counter-rotation of two separate centrifuge arms with two frog canisters on each arm was considered. The use of a counter-rotating weight of different weight and speed was also analyzed. Figure 24 presents the torque compensator diameter versus weight and speed based on a centrifuge moment of inertia of 10.4 slug-ft^2 , a diameter of 6 feet and a 0 to 0.3 g spinup in 8 seconds. A small diameter, low mass wheel can be used for torque compensation, but its high speed presents balancing problems. Also the high speed results in very high power consumption since power is torque times speed. If torque compensation were used it is recommended that a larger diameter (3 foot), heavier (30 lb) wheel run at low speed ($\leq 200 \text{ rpm}$) be used. Figure 25 present the design of a single motor drive to achieve torque compensation that eliminates the need for control of two separate motors. In the single motor design, both stator and rotor move in opposite directions, one carrying the centrifuge and the other carrying the counter-weight. Automatic torque compensation is achieved without motor speed control. The counter weight is accelerated and/or driven to a speed that will result in equal torques.

Based on the complexity of torque compensation designs and the relatively low "g" forces produced by the centrifuge, a torque compensator was not included on the experiment design.

Canister Shape

Cylindrical, spherical, oval, and rectangular canisters were compared during the trade study. The oval shaped canister best fits the shape of the frog thereby providing the least trapped water volume, but would be expensive to fabricate. The sphere is an attractive possibility for three axes positioning if the fluid lines and electrical cables can be readily accommodated, but does result in a high trapped water volume. The sphere can be relatively easily manually positioned and clamped in place. The rectangle does not offer any particular advantage. The cylinder is a convenient shape, fitting the frog fairly well and is the best shape to minimize weight and cost.

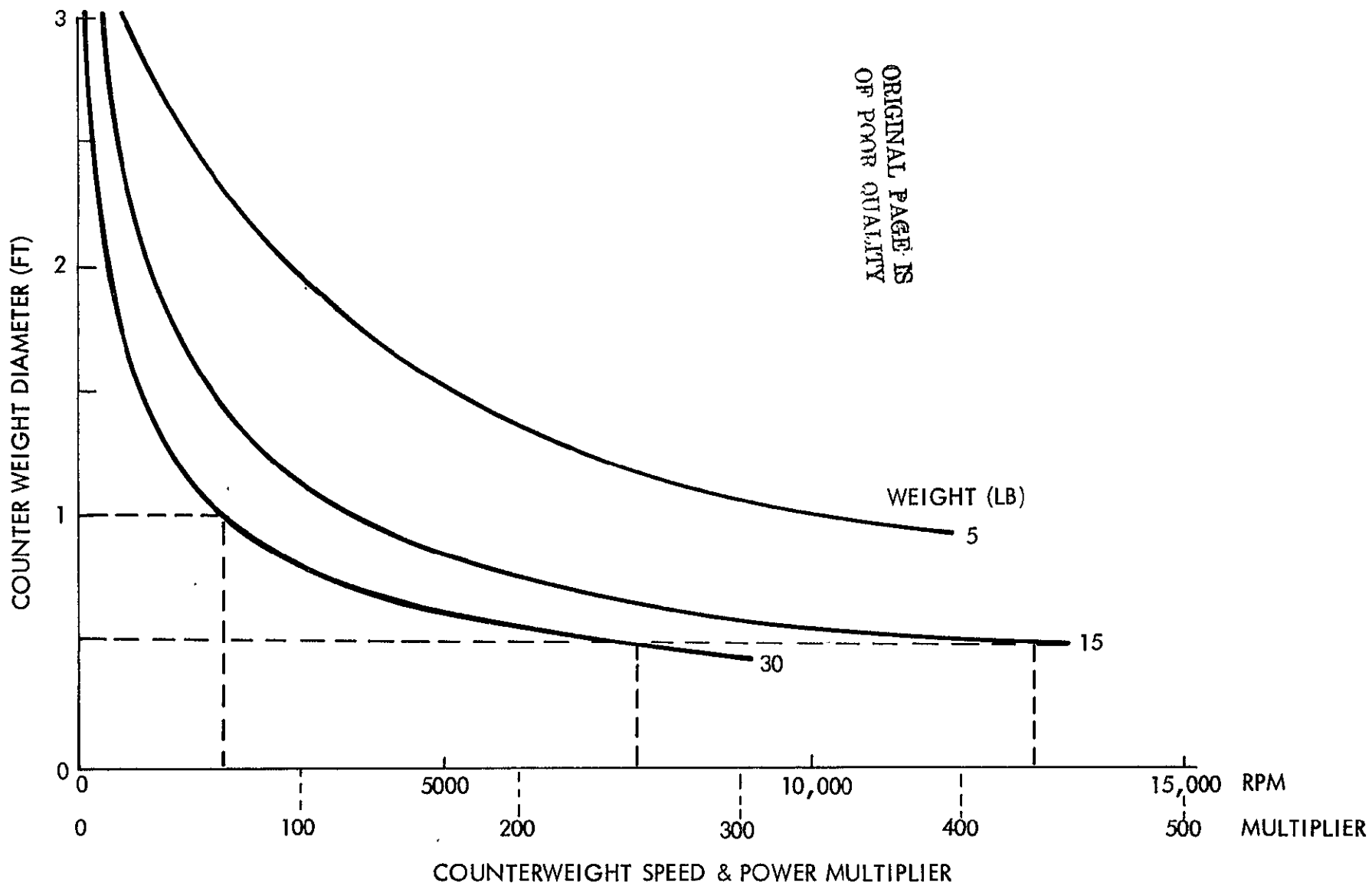


Figure 24 Torque Compensator Size and Weight

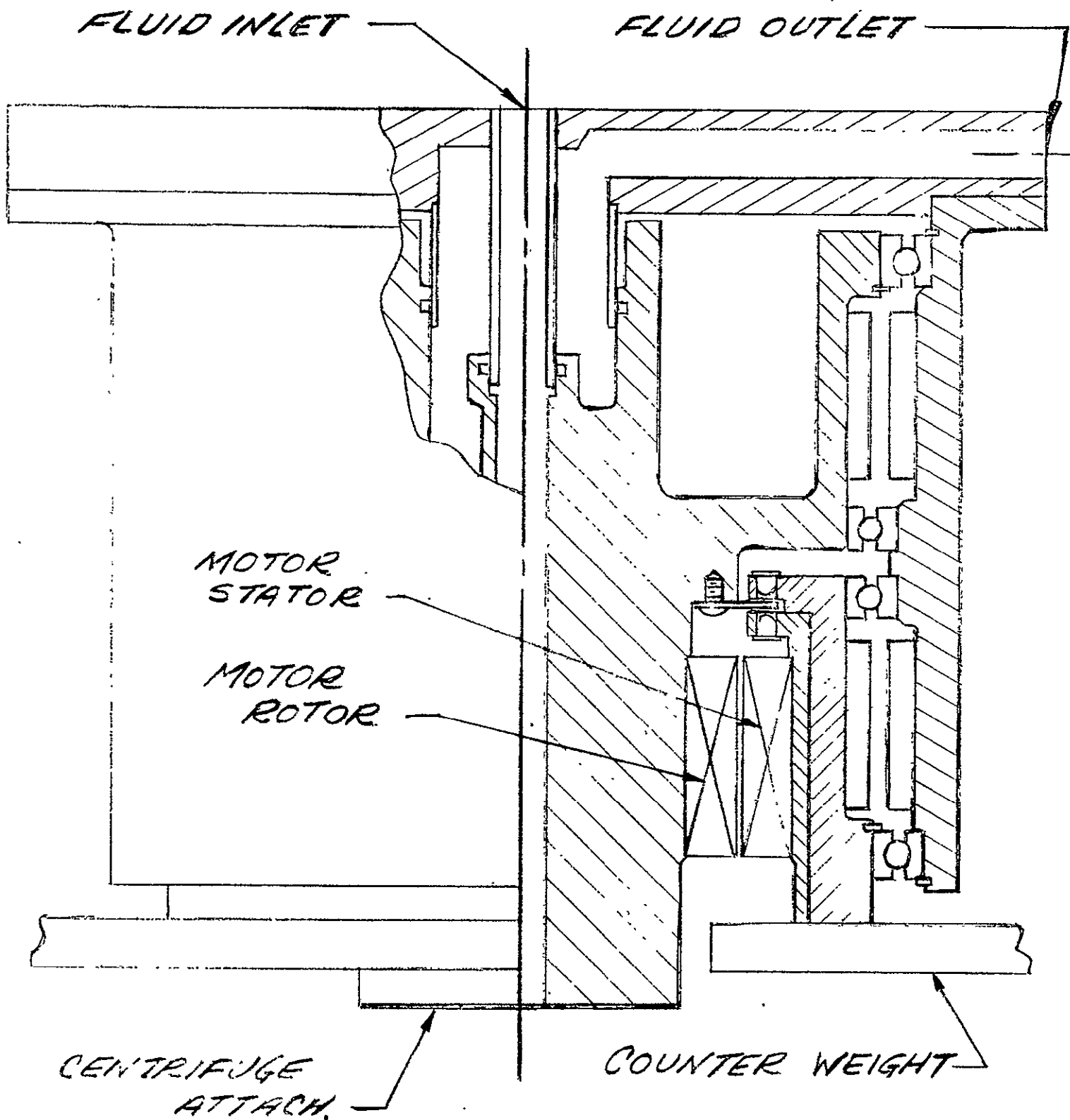


Figure 25 Torque Compensator Design - Single Motor

Centrifuge Beam Structure

Tubular truss, sheet metal and honeycomb centrifuge beam structures were analyzed and compared. The sheet metal construction was eliminated because it was heavier than the other designs. The honeycomb structure did not perform well in the dynamic analysis. The tubular truss looked favorable from both weight and dynamic response standpoints. The final centrifuge structure utilized a single large pipe as the major beam structure augmented with small tubes connected to the center pipe.

Centrifuge Configuration

Three centrifuge configurations were evolved and compared during the trade studies. Figure 26 presents a centrifuge design with the four frog canisters mounted at 90 degrees to each other. This design provides a rigid symmetrical platform for mounting of relatively large pieces of support equipment, if required. It offers the disadvantages of occupying more space in the static position which may limit access to Spacelab mounted equipment when the centrifuge is not spinning, increased weight, and requiring a maximum number of fluid and electrical runs.

Figure 27 presents a centrifuge design with two frog canisters side by side opposite from the other two canisters. This design minimizes the static centrifuge volume, minimizes fluid and electrical runs and provides the lowest weight design.

Figure 28 presents a centrifuge design with one frog canister opposite another on one centrifuge arm which is on top of or adjacent to an identical second centrifuge arm. This design is capable of counter-rotation if desired and occupies a minimum static volume. It requires the most space while the centrifuge is spinning, is the heaviest design and requires balancing of two centrifuge arms.

Because very little equipment is to be placed on the centrifuge and the desire to occupy as little space as possible during all mission phases the concept presented by Figure 27 was selected during conceptual design studies.

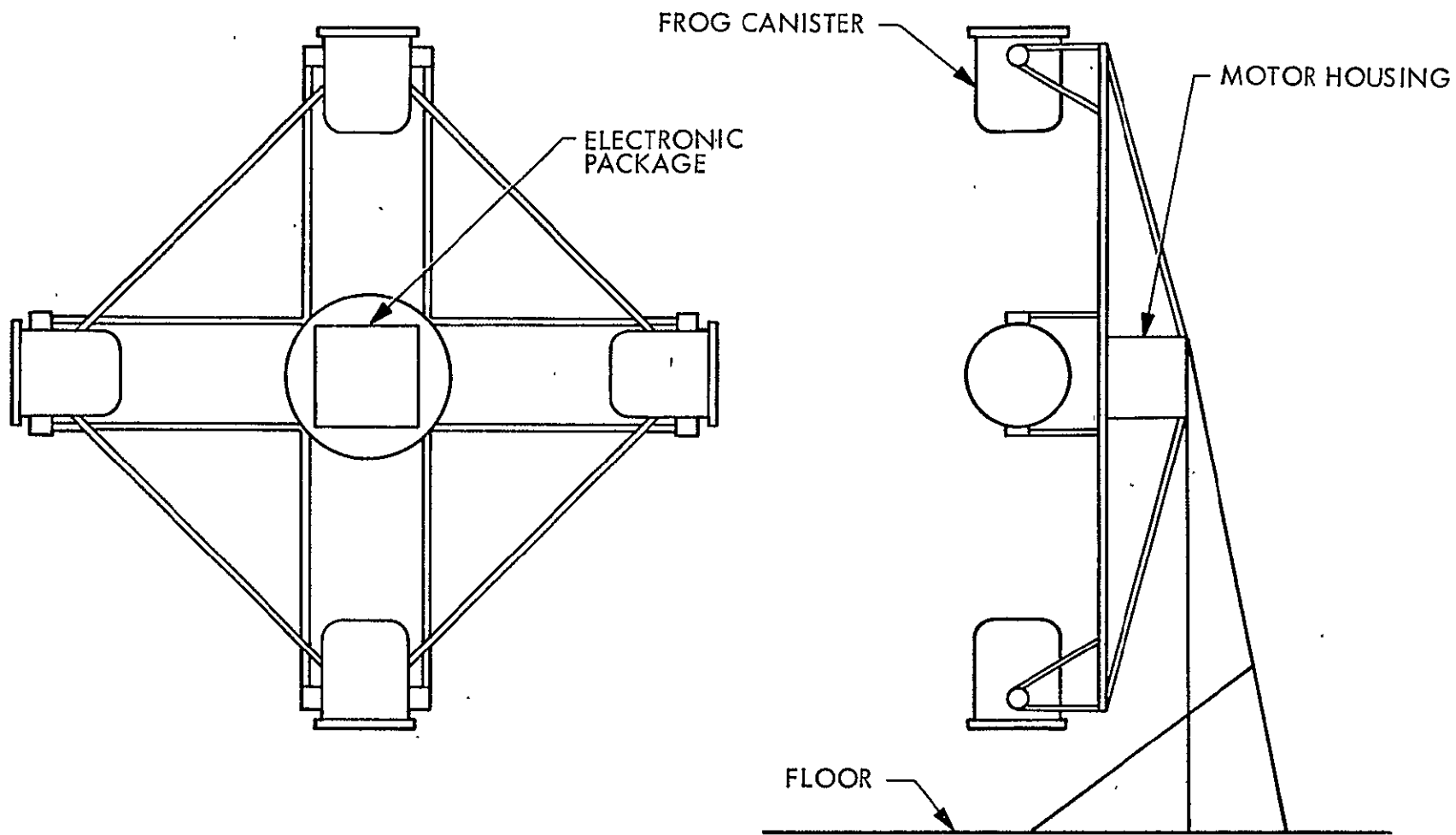


Figure 26 Centrifuge Concepts - 90° Table

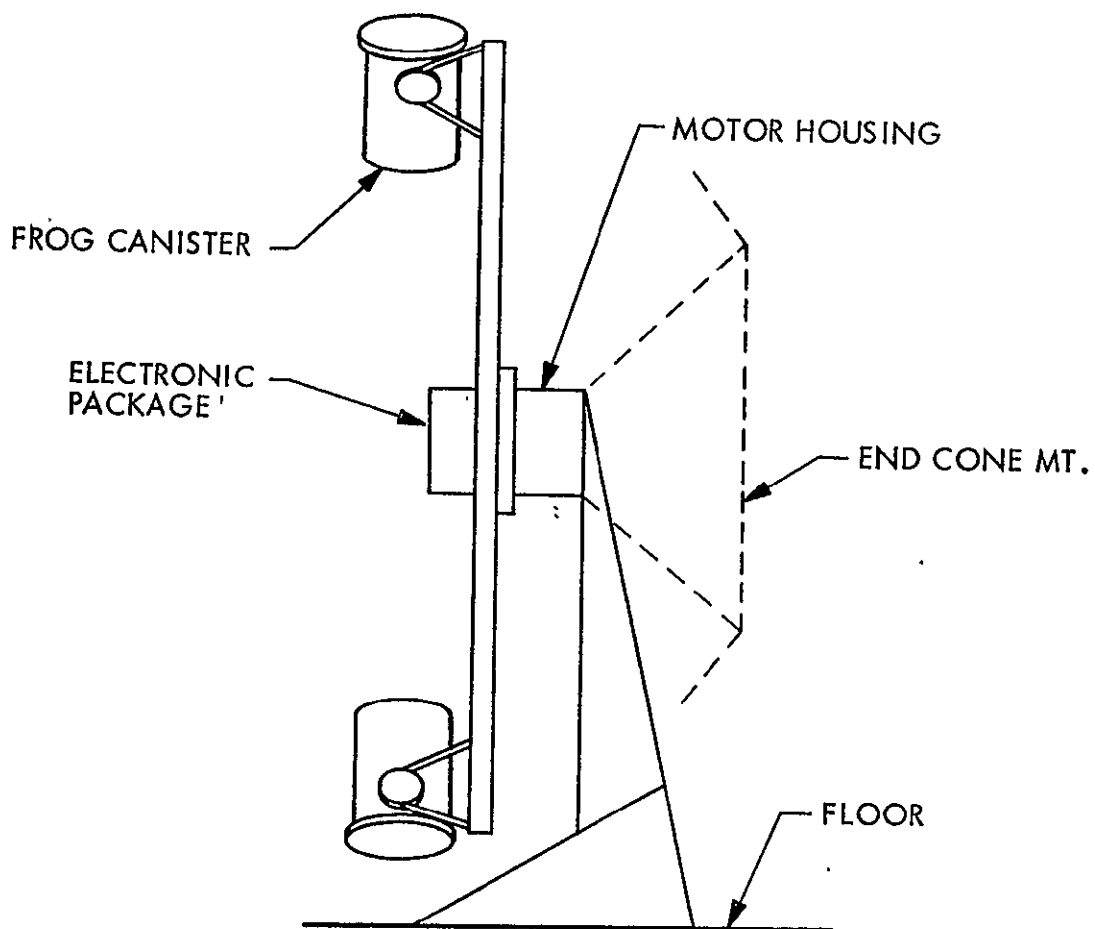
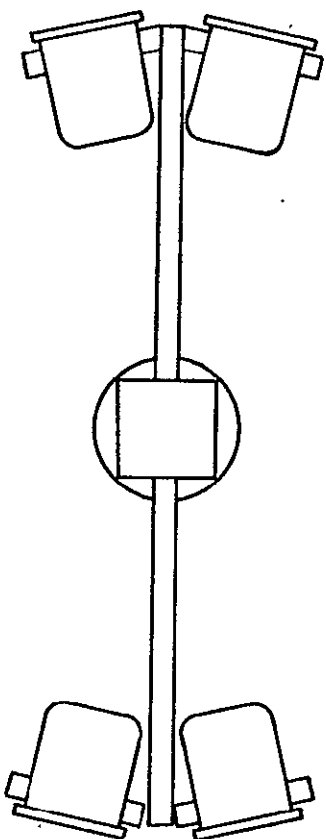


Figure 27 Centrifuge Concepts - 180° Opposed Side by Side

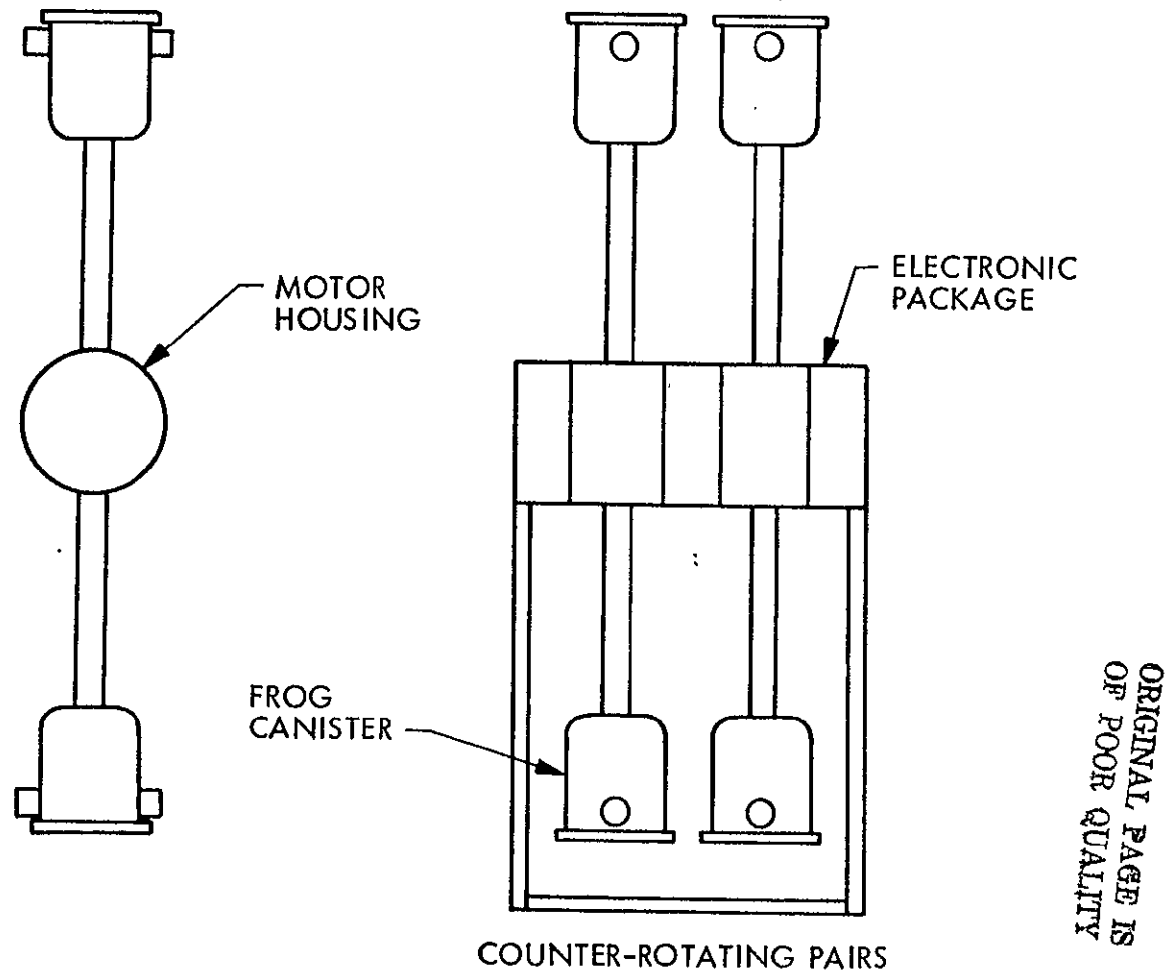


Figure 28 Centrifuge Concepts - 180° Opposed Top to Bottom

Centrifuge Mounting

The Spacelab floor, end cone and rack attachments were considered for centrifuge mount points. The preferred location of the experiment in the aft end cone area had been previously selected during the mission mode study. The Spacelab end cone mount offers the advantage of a very simple light weight, and rugged centrifuge base design, but it attaches to the end cone of the Spacelab module which results in several big disadvantages. It complicates experiment checkout in the prelaunch preparation areas by placing part of the experiment on the removable floor/ESA rack assembly and part of the experiment on the Spacelab shell assembly. It requires modification to the Spacelab end cone for the VFR centrifuge mount and it does not provide the rigidity that the other mounts provide. The floor mount complicates the centrifuge support structure, but does provide an integrated experiment package for each assembly and checkout, requires no special Spacelab structural provisions for the VFR experiment and provides the best support as shown by the dynamic model. The floor and ceiling mount complicates the support structure even further, requires special attach point provisions on the top of the ESA racks and ties two elements together that may move with respect to each other. The floor mount was therefore selected for the VFR design.

Materials of Construction

A review of the experiment requirements was conducted with respect to materials of construction of any element of the system that contacted the frog solution. The necessity of avoiding any ground of the frog solution dictates careful component and materials selection and special design provisions. It is felt that coating of the internal parts of the system after assembly may be helpful, but cannot be used as the primary means of preventing grounding. Coatings are easily cracked and must be reapplied after any disassembly or component removal. Table 7 presents the recommended materials of construction for the components of the fluid system. Table 8 presents a summary of the properties of various non-metallic materials and their suitability for use in a spacecraft system.

Table 7

MATERIALS OF CONSTRUCTION

Specimen Canister - Coated 316 SS with non metallic cover

Specimen Washing Unit - STD motor - non metallic housing and shaft

Filters - Non metallic case - 316 SS screen

Accumulator - Non metallic tank and bladder

H₂O Bleed Tank - Non metallic tank and bladder

Bleed Pump - STD motor magnet drive non metallic pump head

Circulation Pump - STD motor - magnet drive - non metallic pump head

Lung - Non metallic case and membrane

Thermal Electrical Unit - 316 SS heat exchanger isolated by non
metallic bonding of thermal electric modules

Valves - Manual all non metallic

Valves Automatic - Metallic actuator - non metallic body

Fluid Lines - Non metallic

Fittings - Non metallic and isolated 316 SS

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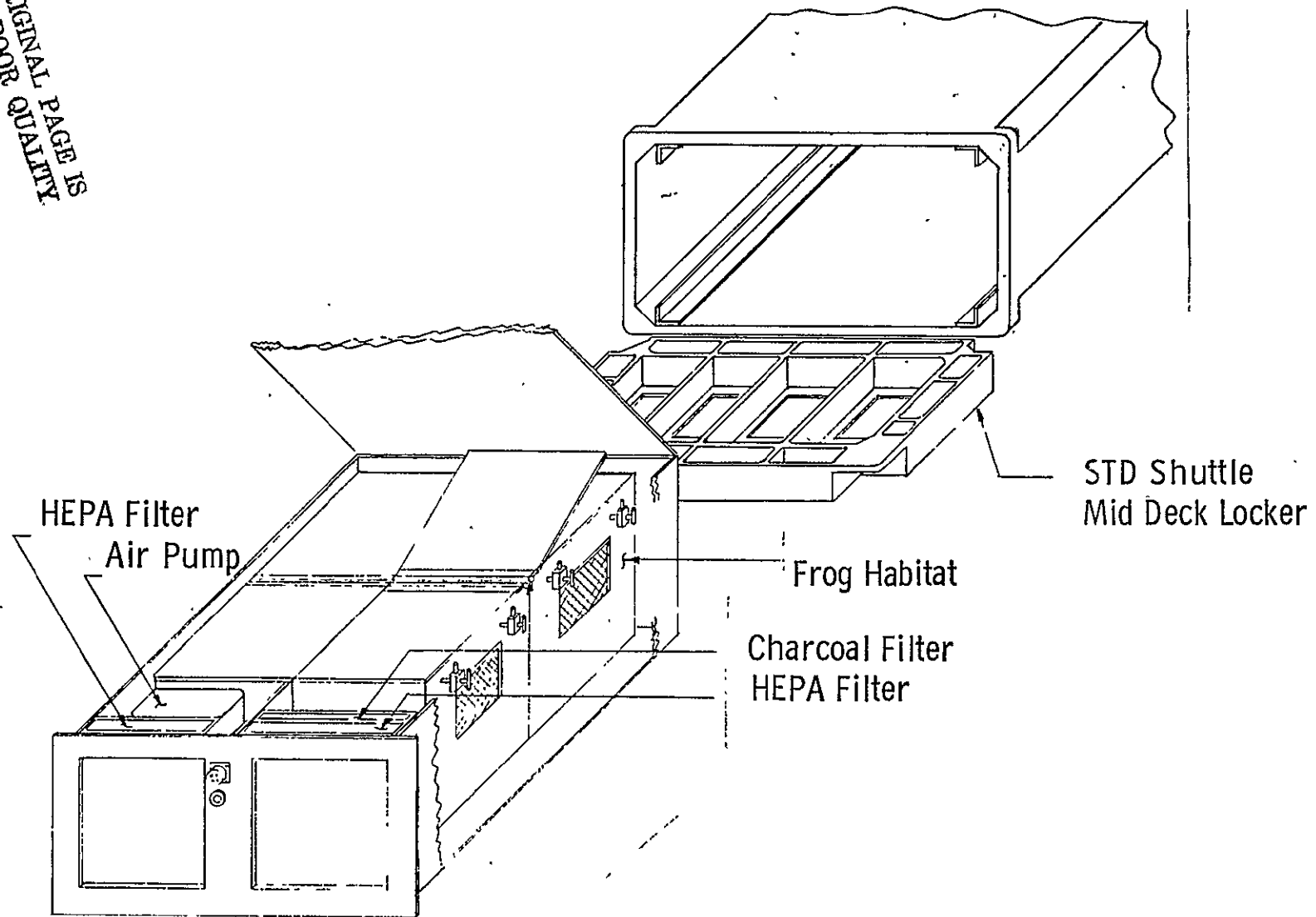


Figure 29 Morphological Study - System Design

be required. A source of D.C. power will have to be provided at a level of approximately one watt per canister for Peltier cooling or TBD watts per canister for pharmacological blocking. The ionphoresis technique is assumed. The data acquisition system will also have to be expanded to include "on/off", "right/left", and possible temperature signals if Peltier cooling devices are used. For optimum cost effectiveness, it is recommended that activation and deactivation of the blocking device be performed manually.

Linear Acceleration

A linear acceleration device, designed into the canister support structure, was evolved, based on the use of four linear ball bearing supports that allow the canister to move toward or away from the center of the centrifuge. One of the bearings is powered by a lead screw to provide the required motive force. A torque motor controlled by the centrifuge microprocessor drives the lead screw at pre-programmed speeds to achieve the desired velocities and accelerations. This option would be relatively easy to accommodate.

Addition of Two Orbiting Control Specimens

The penalties of placing two frogs in the Spacelab rack as non-centrifuged control specimens are presented below. The increases in system size, weight, and power are relatively small. If the mid-deck locker area is used for specimen holding during ascent and descent, the addition of two more frogs will result in the use of six locker areas instead of five.

Dry weight added	33 lbs
Expendable weight added	27 lbs
Power added	25 watts
Increased Cost	\$75 K

Cost of Experiment Options

The estimated cost increases resulting from adding each experiment option is as follows:

o	Negative Receptor Field Testing	\$ 15 K
o	Specimen Positioning - Manual	\$125 K
o	Specimen Positioning - Automatic	\$350 K
o	Tilt Axis Accelerations	\$125 K
o	Morphological Studies	\$250 K
o	Linear Accelerations	\$ 75 K
o	Addition of Two Orbiting Control Specimens	\$ 75 K

PRELIMINARY DESIGN

A preliminary design based on the results of the mission mode and conceptual design studies was conducted to define the centrifuge and rack mounted equipment, the mission operations aspects of the program, and program plans. Equipment design studies included acoustic noise testing, dynamic modeling of the centrifuge and support structure, component design and system level design.

Acoustic Noise Protection

Acoustic noise levels within the frog canisters must be limited to a maximum of 100 db. The critical design loads are imposed during ascent shortly after rocket engine ignition. The sound pressure level, and frequency and time distribution have been previously presented. A peak of 136 db occurs in the Spacelab Module during ascent. A canister or system design that will attenuate the external acoustic field by 36 db is required. An analytical prediction of the performance of different design concepts is an extremely difficult task, that would not lead to results that could be used with high confidence levels. To evaluate different approaches to sound control, several specimen canister configurations were built and tested in a reverberant acoustic chamber. The excitation spectrum used in the tests was that presented in the Spacelab Payload Accommodations Handbook. Each container was filled with water and a hydrophone measurement was made of the resulting sound level in the canister. The configuration of the four canisters tested are presented by Figure 30.

The first configuration tested, Figure 30a, was a 0.030 inch thick stainless steel cylinder, 6 inches in diameter, 8 inches high and fitted with an 0.125 inch thick aluminum end-plate. With this design the internal levels measured were as high as the external levels, namely 136 db. The second and third configuration tested are shown in Figures 30b and 30c. The intent of the design shown in Figure 30b was to reduce the acoustic

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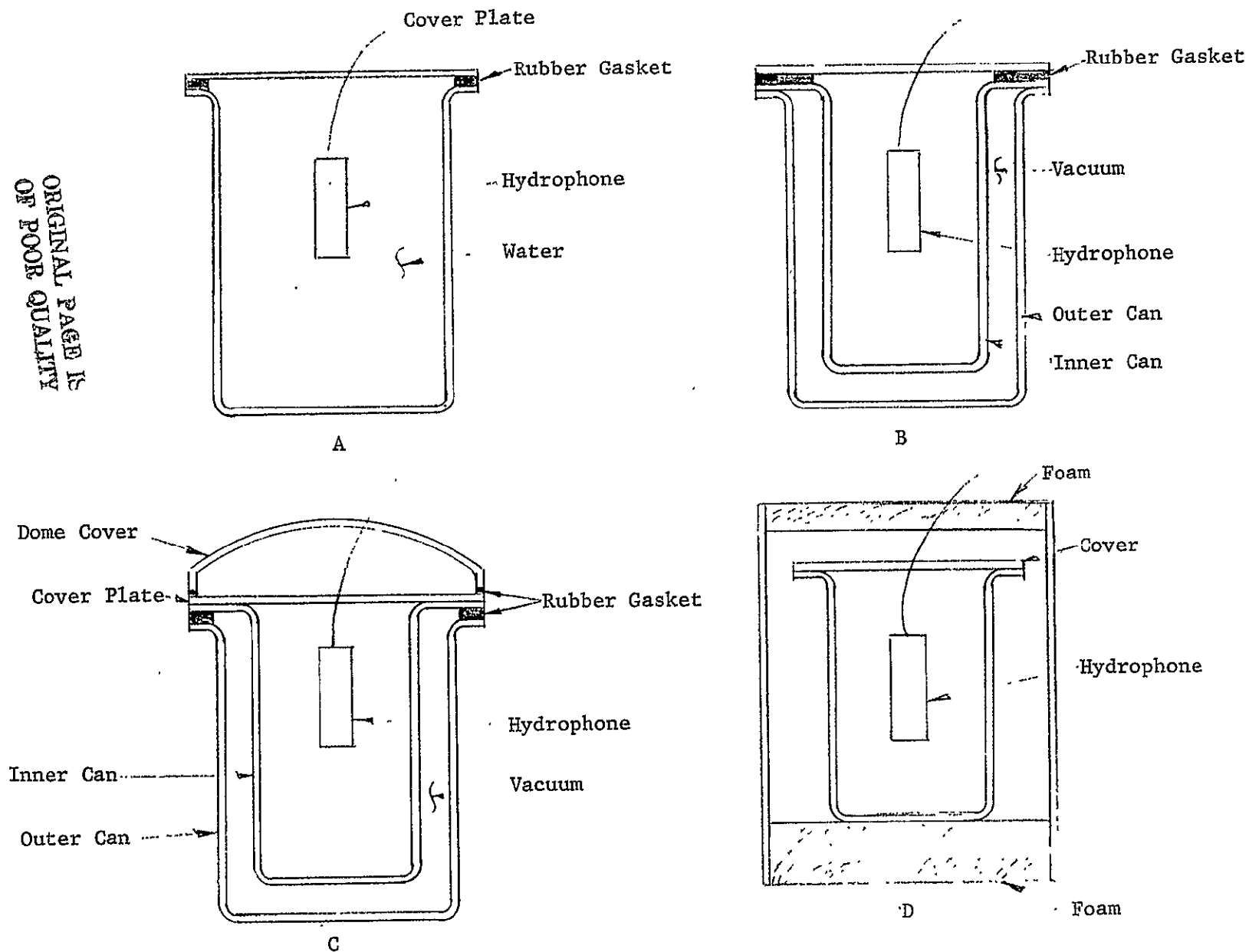


Figure 30 Canister Configurations for Acoustic Tests

energy being transferred directly through the cylindrical shell of the frog container. This was to be accomplished by using a double cylinder with a vacuum between the shells. When tested this design provided 5 db of noise reduction resulting in an internal level of 131 db. The third configuration, Figure 30c, was the same as the one just described except protection was provided for the end-plate and a soft rubber gasket 0.25 inches thick was inserted between the frog container and the outer shell. The purpose of the rubber gasket was to keep the external shell from mechanically exciting the shell of the frog container and transmitting this energy into the water. When tested these modifications did not improve the 5 db of noise reduction previously obtained. A number of "tap" tests were then performed on the outer shell and it was found that only when the frog container was completely detached from the outer shell could any significant change be made in the underwater acoustics. Apparently a primary mechanism for transmitting energy from the external acoustic field is that whereby the acoustic induced excitation of the outer shell couples mechanically with the walls of the frog container and the resulting vibration excites the water within. This conclusion is supported by the results of a test performed on the configuration shown by Figure 30d. Here the frog container is not connected directly to the outer shell and the entire frog container sets within an outer shell on soft foam. The space between the shells is not evacuated. When tested, 20 db of noise reduction was obtained resulting in an internal acoustic level of 116 db.

It was therefore decided to reduce the mechanical vibration being transmitted into the frog container by changing from the thin double wall construction into a single wall $\frac{3}{8}$ inches thick. Since the compliance of the shell is inversely proportional to the thickness, this design should reduce vibration by 20 db with respect to the 0.030 inch skins used for the double wall construction. Whether this results in 20 db of noise reduction remains to be established since this final configuration was not tested due to lack of time. Adequate protection of the frog specimen from the acoustic noise spike of launch requires further testing

and development effort to establish a design that doesn't over complicate the canister, allows unattended operation of the centrifuge prior to Spacelab activation, and yet provides the required degree of noise attenuation.

Centrifuge Design

Following the conceptual design studies, it was decided that the design options of manual specimen positioning, negative receptor field testing and addition of two orbiting control specimens would be included in the preliminary design. In laying out a design that would satisfy these options, it was established that canister size and positioning equipment increased centrifuge arm size and weight so greatly that the 180° opposed side by side canister centrifuge concept selected earlier in the study was no longer feasible. The canister support structure that accommodates the manual positioning of the specimens was so wide that the canisters would be separated so far apart that the centrifuge structure approached that of a table with canisters at 90° to each other. Therefore, the centrifuge design was changed to be a table.

Figures 31, 32, and 33 present the centrifuge, canister and canister gimbal and centrifuge hub assembly designs. The centrifuge consists of six major assemblies; the base mount, the drive hub assembly, the centrifuge frame, the canister support structure, specimen canisters, and the centrifuge guard.

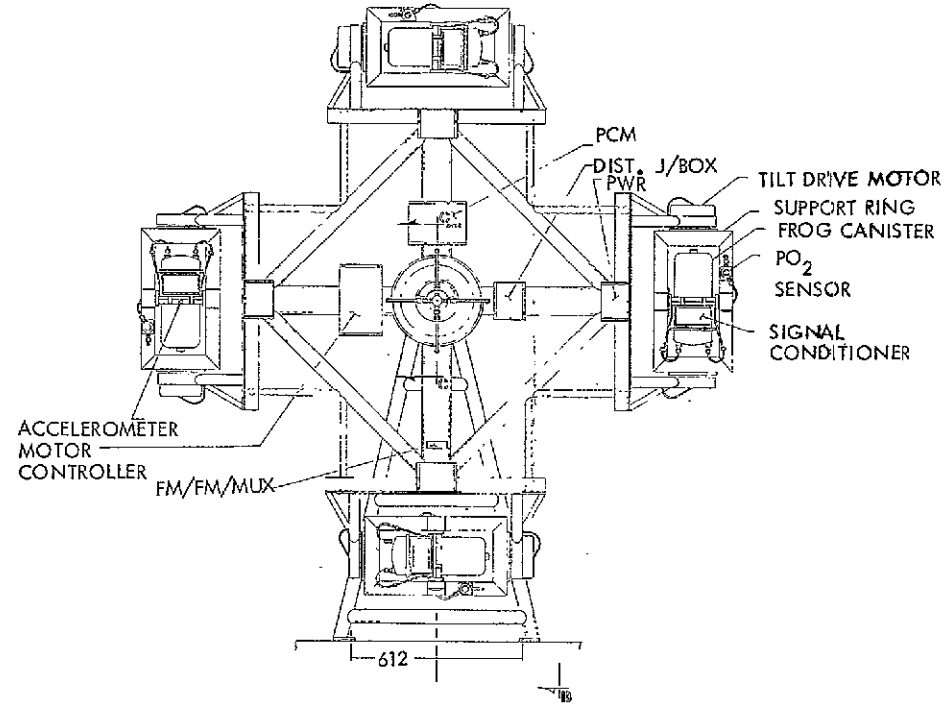
Centrifuge Mount

The centrifuge mount is a welded aluminum tubular truss structure. The four main corner posts are 2 inch dia. tubes which are welded to mounting pads at the base and to the drive hub support flange at the top. The four corner posts are connected with tubular truss members. One corner post houses the inlet and outlet fluid lines. These lines are held in place and insulated using foam in place urethane foam. The electrical and data transmission lines are housed within another corner post.

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FOLDOUT FRAME



FOLDOUT FRAME 2

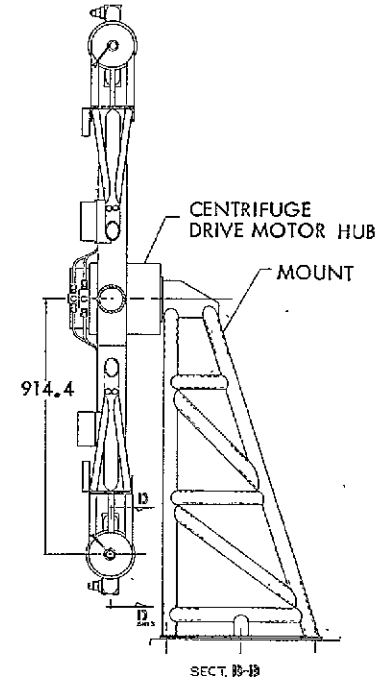


Figure 31 Centrifuge Assembly

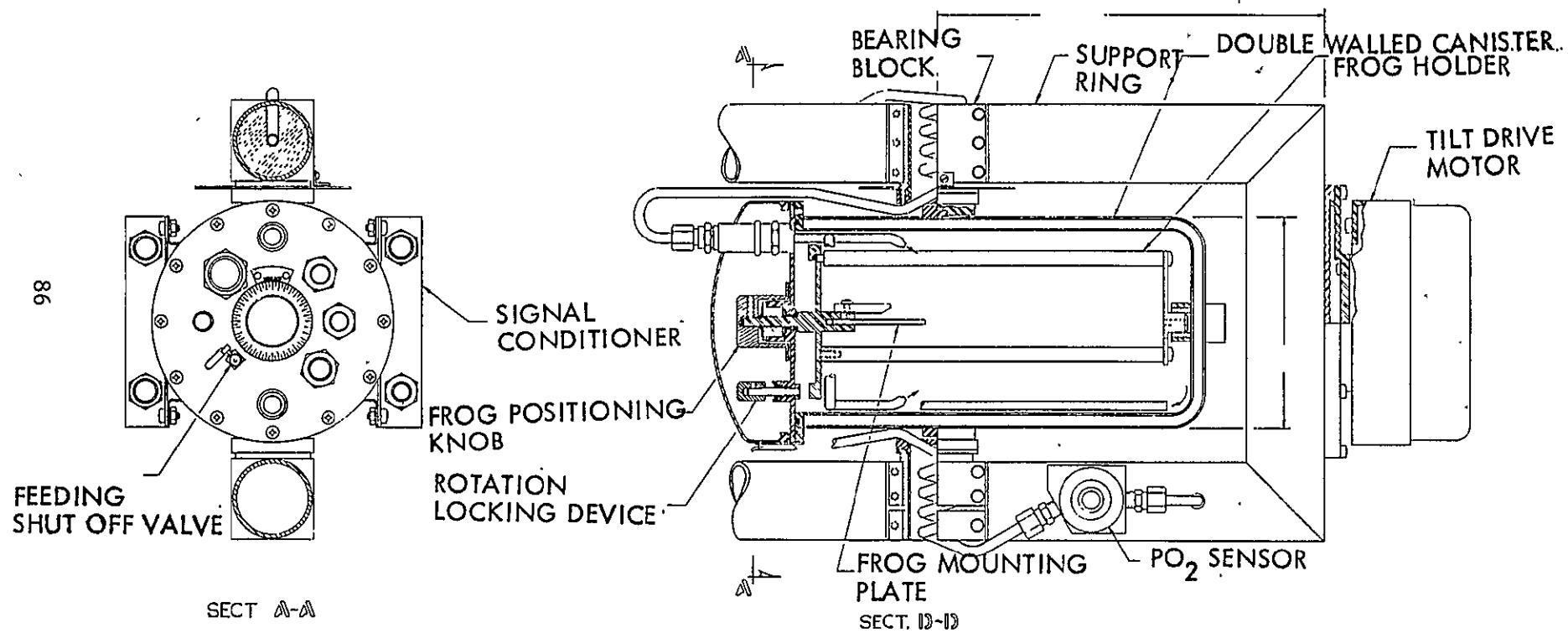


Figure 32 Specimen Canister and Gimbal Assembly

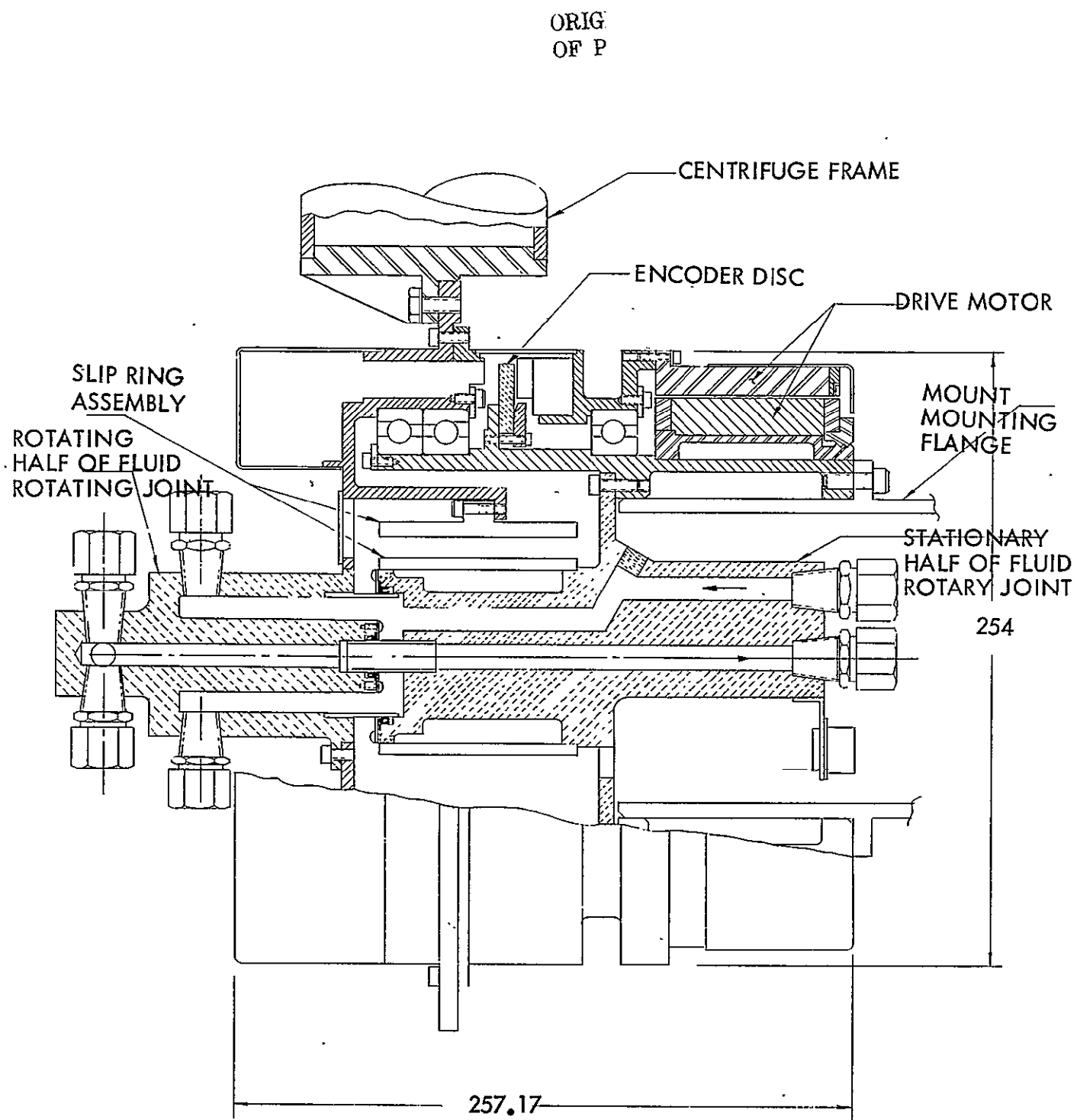


Figure 33 Centrifuge Drive Hub Assembly

These lines terminate at electrical connectors mounted on the drive hub support flange and a connector plate at the base of the mount adjacent to a through the floor access plate. The fluid lines and the electrical power and data wires run under the floor to rack 12 where the life support and data system electronics are located. The mount is attached to the floor using the last six hard mounting points in the center aisle in the aft end of Spacelab.

Drive Hub Assembly

The centrifuge drive assembly is a B.E.I. Electronics Inc. 1190 series absolute position encoder drive unit modified to accept a rotary fluid joint and slip ring assembly. This unit consists of an outer and inner aluminum housing. Within these housings are mounted the drive motor, optical encoder, bearings, electrical slip rings, slip ring brush assemblies, rotary fluid joints, and base mount and centrifuge body flanges. The outer housing rotates and contains the drive motor rotor, encoder electronics, photo detectors, electrical slip ring brush assembly, the centrifuge body mounting flange and half of the rotary fluid joints. The inner housing mounts the drive motor stator, the encoder code disc, the base mounting flange and the other half of the fluid rotary joint. These housings are aligned with each other and rotate using a pair of duplex preloaded bearings on one end and a single bearing at the other end. The bearings used are Fafnir Precision Instrument ball bearings. The fluid rotary joint assemblies are constructed of plastic and are mounted separately to the inner and outer metal housing. The rotary seal is a Teflon spring load "C" shaped Bal-Seal. The seals are mounted on the stationary member of the rotary joint. The rotating member has polished metal inserts which rotate against the Bal-Seal. The fluid enters and leaves the rotary joint through swagelok high density polyethylene fittings that are integral with the stationary and rotating bodies. The electrical slip ring assembly is mounted on the stationary rotary joint body. The unit is designed so that the slip ring brush assembly and the fluid rotary joint seals may be easily serviced and inspected from the open end of the drive hub.

Centrifuge Frame

The centrifuge frame is a modified aluminum tubular truss structure emanating from a center hub. The center hub contains the flange which attaches the frame to the drive assembly. The frame is configured to support the four specimen canisters equally distanced from the rotational axis and spaced 90° apart. At the end of each structural arm is attached a channel section. This channel section is mounted perpendicular to the rotational axis with its ends supported by small tubes connected back to the main structure. The fluid lines are contained within the main tubular members radiating from the center hub. The fluid lines are held in place and insulated with foam in place urethane. The power distribution "J" box, microcomputer, FM-FM multiplexer and drive motor controller are mounted and located on the structure arranged to provide dynamic balancing of the centrifuge.

Canister Support Structure

The canister support structure includes a canister support ring, tilt motor drive and bearing housing assemblies. The canister support assembly is bolted to the channel section at the end of each main radial arm of the centrifuge frame. This bolted interface allows the assembly to be removed and replaced by a spare unit eliminating long down times for repair or servicing.

The canister support ring houses the manual rotation Z axis bearing blocks and the X axis automatic tilt motor drive and encoder, and the bearing housing assemblies. The Z and X axis center of rotation pass through the specimen canister center of gravity and the specimens otolith. The Z axis bearing blocks house the canister rotational shaft, shaft locking device, angular location protractor vernier and rulon plastic bearings. The fluid and electrical lines are coiled and pass through the hollow Z axis shaft allowing the canister to be rotated $\pm 180^{\circ}$ around the Z axis. The Z axis shaft which support the canister is mounted in plastic bearings to electrically isolate the canister

from the centrifuge structure. Between the bearing shafts is the canister quick disconnect ring that allows the insertion and a removal of individual canisters by activating four quick acting Nielsen VHC 340-2 clamps. On one end of the X axis support ring, a BEI Electronics 5V680 series absolute position encoder tilt drive motor is mounted and on the opposite end is a bearing housing assembly that uses a Fafnir custom precision extra thin series P/N AVW104K12000 CRV KG-80 ball bearing; attached to both the drive assembly and bearing housing is a tubular "A" frame that is welded to the plate that bolts to the channel section on the centrifuge frame.

Specimen Canister

The canister that houses each specimen is a double walled capsule with sound damping foam between the walls. All of the penetrations and internal specimen rotation controls are located on a plate covering the open end of the canister. This end cover plate mounts the specimen rotational location protractor and rotational locking device, specimen data signal feed through connectors, fluid line quick disconnects, and specimen feeding shut off valve. The specimen is rotated $\pm 180^\circ$ manually by a knurled knob on the end cover. Attached to the knob is a protractor marked in 1° increments. Adjacent to the protractor is a vernier allowing the specimen to be positioned within 0.2 of a degree. An adjacent knurled knob activates a brake securing the specimen holder within the canister. The electrical signals pass through the end cover using hermetically sealed cannon KPTH series connectors. The specimen is fed using a syringe which is manually mated to a female luer connection on a one way stop cock valve, that is attached to the end cover. The end cover and all the rotational controls are covered by a foam lined dome used to dampen out the acoustical vibration during launch.

Inside of the canister, the signal leads and the plastic feeding tube leading from the connectors and shutoff valve are coiled between the end cover plate and the front plate of the specimen holding fixture allowing rotational freedom for the specimen within the canister. The leads and

tube are secured to the holding fixture front plate using adel type clamps.

The fluid enters and leaves the canister through Seaton-Wilson Z-1450 series zero-air quick disconnects mounted on the cover plate. The fluid entering the canister passes through a manifold ejecting fluid to the specimens body. There are two nozzles located 180° apart just behind the specimens head. These nozzles are used for low flow life support fluid and high flow washing to remove the sluffing off skin. The fluid return line is located near the back of the canister to assure a good flow through pattern. The specimen holding fixture within the capsule consists of two end plates spaced apart by three rods, equally spaced around the outer edge at 120°. One of the rods is removable to allow insertion of the specimen. The front end plate incorporates a bracket for securing the specimen and allowing fore and aft adjustment to permit placing the specimens otolith on the centerline. The shaft that penetrates the cover plate allowing specimen Y axis rotation is also part of the front plate. The rear plate has a stub shaft that rides in a bearing block that is incorporated in the back inner wall of the capsule.

Centrifuge Guard

Due to the inherent danger resulting from rotating equipment located in inhabited areas, a centrifuge guard has been provided to protect the astronauts and to prevent object floating in a zero gravity environment from coming in contact with the spinning centrifuge. The guard shown by Figure 34 is split into two halves. Each half has an aluminum structural frame covered with a ¼ inch 20 guage flattened expanded aluminum screen. The frames are joined in the center and attached to the center drive hub of the centrifuge, the floor, and the aft side of the equipment racks. There are two access doors provided in the guard, one in each half, allowing access to the specimen canisters for manual positioning between spin cycles. The specimen canisters are also installed and removed through these access doors. The safety equipment normally mounted on the aft cone of Spacelab will be relocated in an accessible area in one of the aft racks or on the centrifuge mount structure.

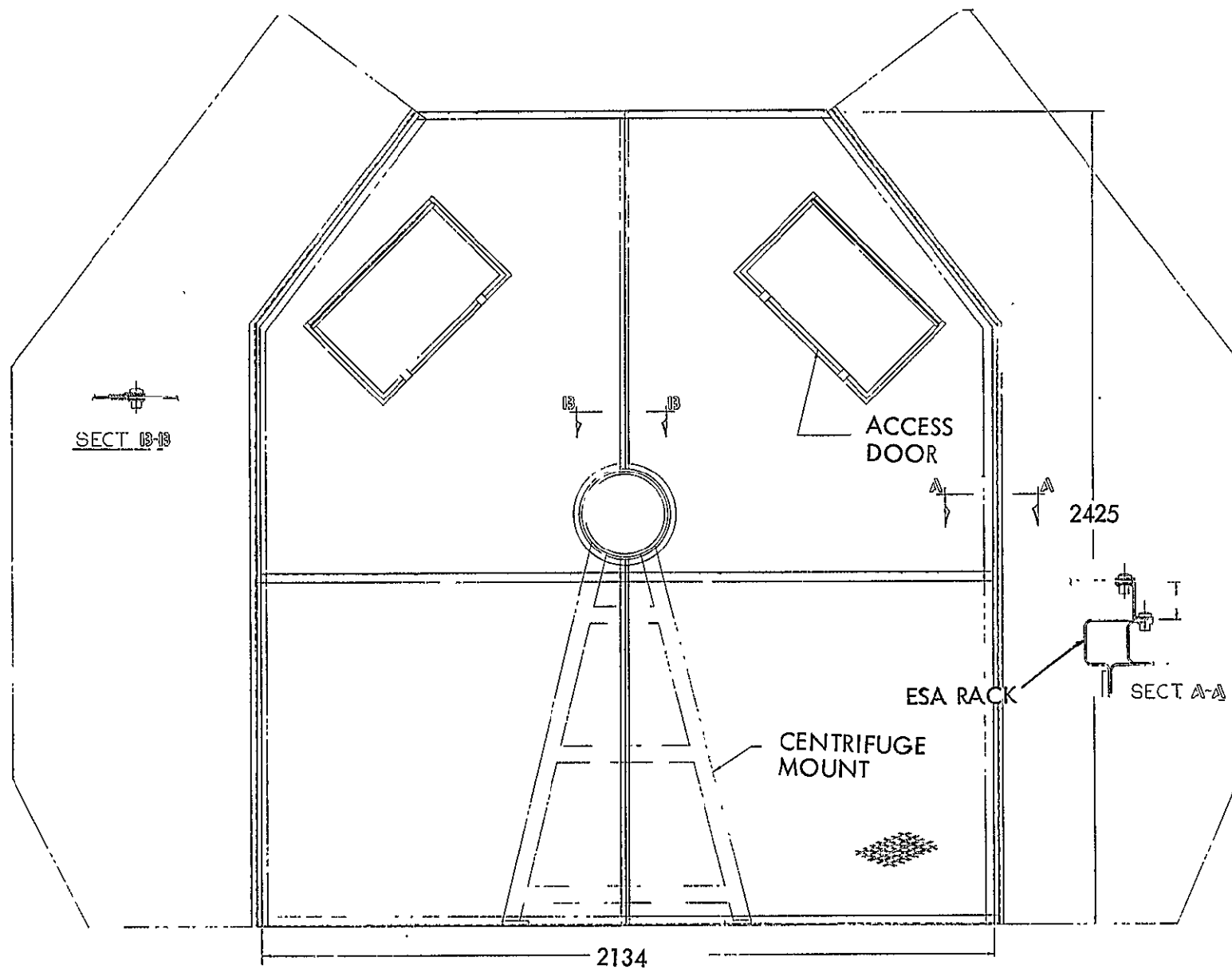


Figure 34 Centrifuge Guard

Centrifuge Dynamic Model Analysis

A dynamic analysis was performed on a computer model of the VFR experiment centrifuge. The model, shown in Figure 35, consists of finite-element beams assembled according to the geometry of the centrifuge, canister assemblies and mounting structure. The weights used in the model are shown in Table 9. The canisters were modeled as rigid masses with rotational inertias and the masses of the motor and electronic boxes were lumped at the attach point of the hub to the base stand.

The dynamic analysis included the preparation of a computer model to determine 'cantilevered' mode shapes and frequencies from a freed condition with the Spacelab mass lumped at the base. Base excitations were applied and also, separately, an unbalance force resulting from spinning the centrifuge arms was applied at the hub to determine structural responses. The resulting acceleration time histories were then used to determine the shock spectra which simulates the frog's head acceleration by considering a single degree of freedom oscillator being tuned to the frequencies within a 1-100 Hz band in order to determine the amplification.

Two of the more critical mode shapes resulting from this analysis are shown by Figure 36. The 20 Hz mode on the left is a rocking mode of the hub and arms on the base stand, while the 28 Hz mode on the right is a local mode of one of the canister assemblies with some base stand motion included. The dashed lines represent the undeformed structure while the solid lines represent the deformed structure (mode shape). The deformation is greatly exaggerated for plotting purposes, so that relative motion can be shown and weaknesses in the structure readily observed. As can be seen from both views, the deformations in the upper portion of the base stand tend to have a significant affect on each mode.

The four forcing functions defined by Figure 37 were analyzed as separate cases. Case 1 represents the arms of the centrifuge being spun in a zero-g

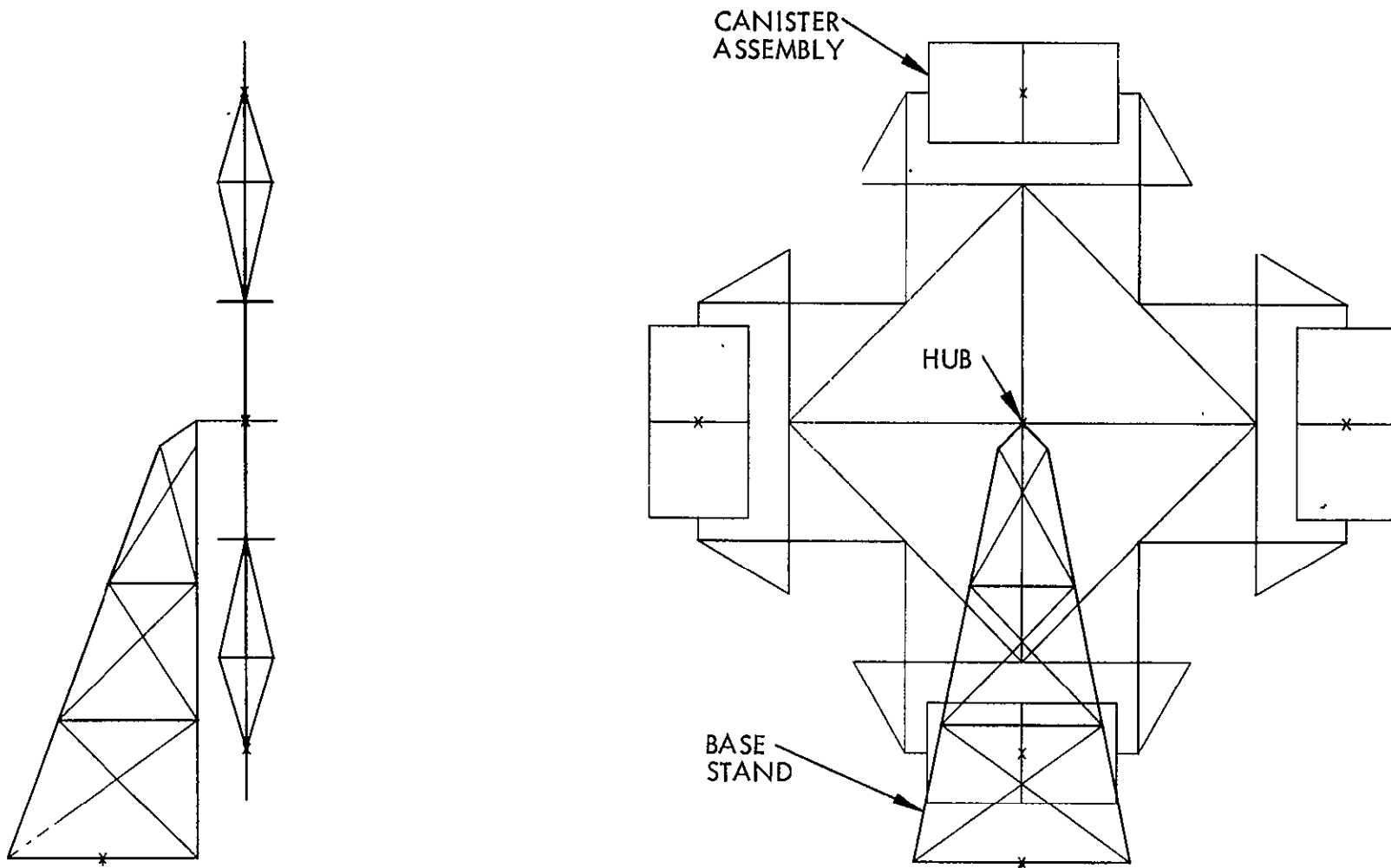


Figure 35 Configuration of Dynamic Model

<u>CONFIGURATION SUBSTRUCTURE</u>	WEIGHTS (lbs)	(AS MODELED)
CANISTER ASSEMBLY	33.2	
CANISTER ASSEMBLY	33.2	
CANISTER ASSEMBLY	33.2	
CANISTER ASSEMBLY	33.2	
HUB AND ARMS	65.8	
BASE STAND, MOTOR, AND ELECTRONIC BOXES	157.9	
TOTAL WEIGHT	= 356.5	
<u>ROTATING WEIGHT FROM ABOVE</u>	=	
4 CANISTER ASSEMBLYS + THE HUB AND ARMS	= 198.6	
<u>CANISTER FROM ABOVE ASSEMBLY</u>	= 25.0	
<u>MOTOR AND ELECTRONIC BOXES FROM ABOVE</u>	= 90.0	

Table 9 Weight Summary For Dynamic Model Analysis

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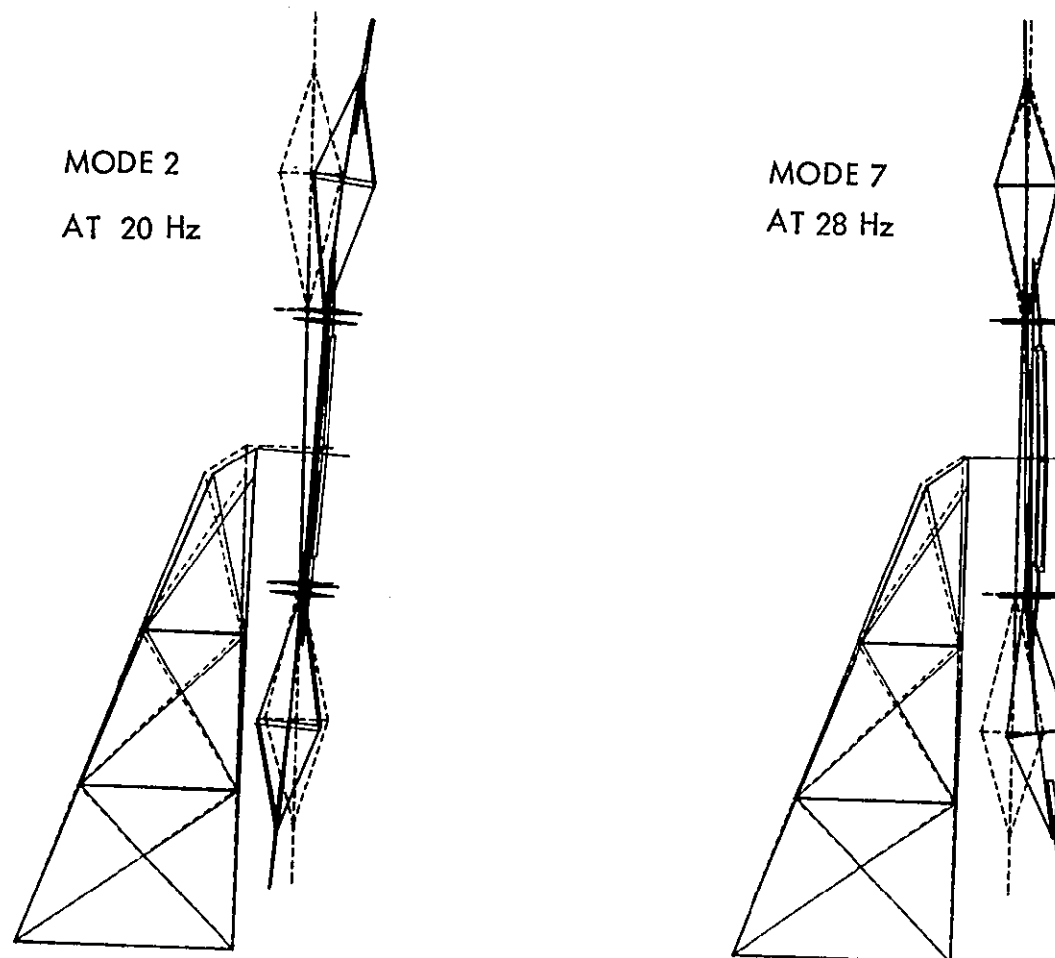
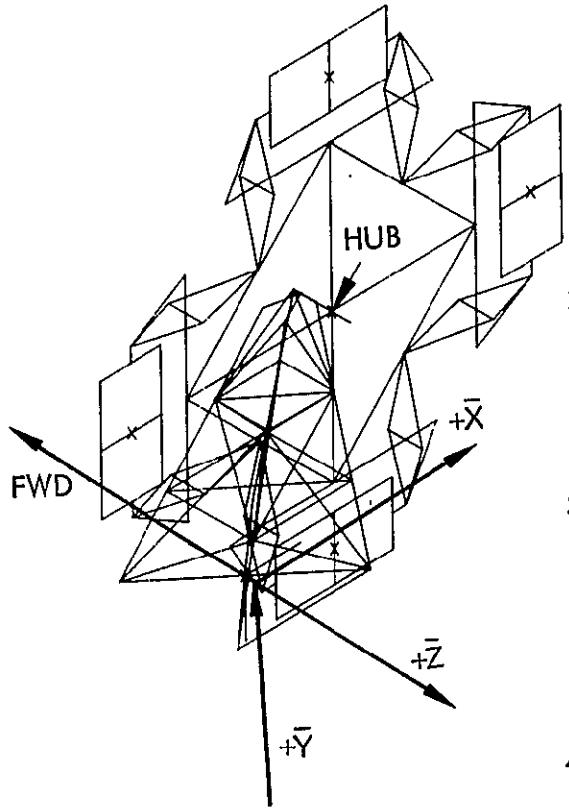


Figure 36 Critical Dynamic Motion



CONDITION	APPLICATION	FUNCTION
1 32 RPM SPINNING (SPACE)	UNBALANCE OUTWARD RADIAL FORCE OF $\Delta M \cdot R \cdot \omega^2$ AT HUB	
2 VERNIER THRUSTERS (EUROPEAN SPACE AGENCY TRANS- LATIONAL DATA)	$2.17 \times 10^{-4} \bar{X} \text{ g}$ $-2.48 \times 10^{-4} \bar{Y} \text{ g}$ ON FLOOR AT EXPERIMENT	
3 VERNIER THRUSTERS (MARSHALL CENTER DATA, MISSION #3)	$1.40 \times 10^{-4} \bar{X} \text{ g}$ $-2.80 \times 10^{-4} \bar{Y} \text{ g}$ $1.30 \times 10^{-4} \bar{Z} \text{ g}$ ON FLOOR AT EXPERIMENT	
4 CREW MOTION (MARSHALL CENTER DATA, MISSION #3)	$3.40 \times 10^{-4} \bar{X} \text{ g}$ $3.40 \times 10^{-4} \bar{Y} \text{ g}$ $3.40 \times 10^{-4} \bar{Z} \text{ g}$ ON FLOOR AT EXPERIMENT	

Figure 37 Defining Forcing Function

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field from startup to its running speed of 32 rpm. This forcing function was defined for an unbalance weight of ΔW at a location radius r from the hub. The unbalance force (f) at a centrifuge angular velocity (ω) is:

$$f = \frac{W}{g} r \omega^2 = Mr \omega^2 \quad \dots(1)$$

from which the hub forces may be applied as:

$$F_x = f \sin \omega t$$

$$F_y = -f \cos \omega t$$

so that the resultant of the outward radial force (F_R) is:

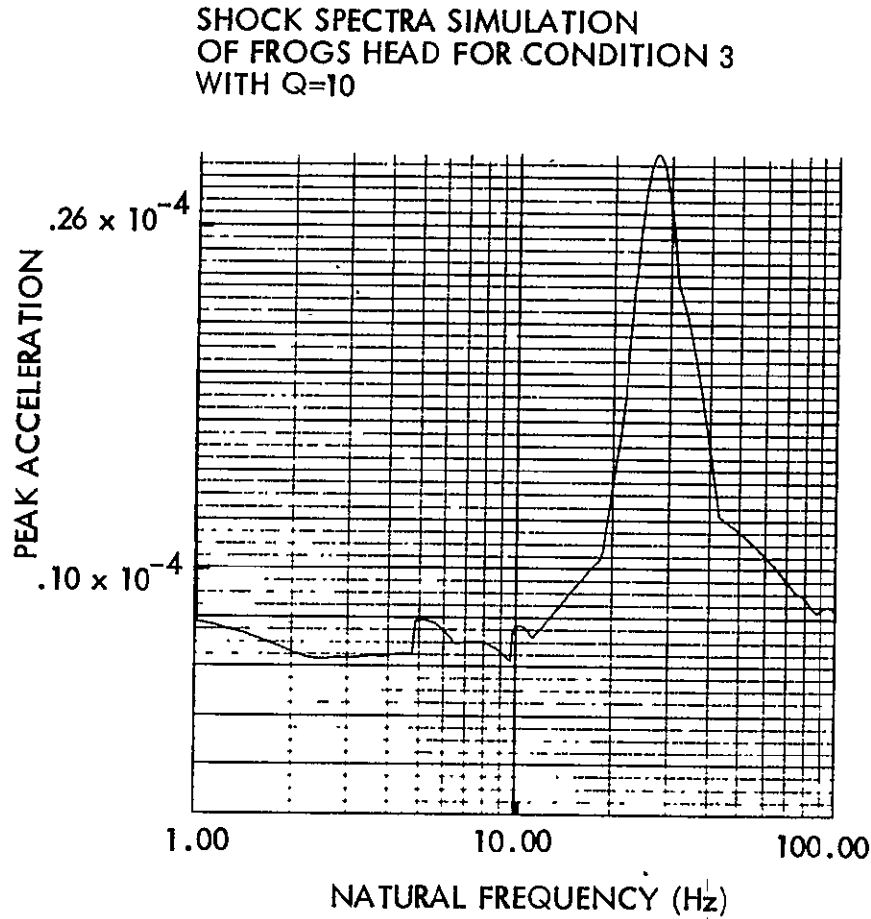
$$F_R = \sqrt{F_x^2 + F_y^2} = f \quad \dots(3)$$

Also the value of ω is varying linearly with time.

Cases 2 represents base excitations for the vernier thrusters as specified by the ESA report SLP/2104 30 June 1977 in Table 5-13. The full values of the translational data were input, as a conservative estimate, without regard to the distance from the orbiter center of gravity.

Cases 3 and 4 represent base excitations for the vernier thrusters and crew motion respectively as specified by Marshall Space Flight Center, systems dynamics laboratory, spacelab mission #3, by R. C. Lewis in December 1977.

The results of the forcing functions are shown in Figure 38. The table on the right shows the maximum acceleration response (Mg) for the various cases and locations considered. Inspection of the results presented in Figure 38 show that all accelerations are below the design limit of 1 Mg. The responses for the floor and canister locations were obtained directly by applying the forcing function to the modes and frequencies of the system. The response of the frog, since it was not modeled in the structure, was simulated by doing a shock spectra evaluation of the acceleration response time history of the canister location with a single degree of freedom



		OUTPUT		
		LOCATION	ACCEL. Mg	FREQ. Hz
1	SPINING O-g	FLOOR	$.701 \times 10^{-5}$ ΔW_r	
1	SPINNING O-g	CANISTER	$.701 \times 10^{-5}$ ΔW_r	
1	SPINNING O-g	FROG	$.724 \times 10^{-5}$ ΔW_r	8
2	ESA VERNIER	CANISTER	.0012	
2	ESA VERNIER	FROG	.0034	38
3	MARSHALL VERNIER	CANISTER	.0080	
3	MARSHALL VERNIER	FROG	.0270	28
4	MARSHALL CREW	CANISTER	.0022	
4	MARSHALL CREW	FROG	.0042	34

Figure 38 Results of Forcing Functions

oscillator as mentioned previously. A typical shock spectra for the frog is shown on the left for condition 3. In all cases, a $Q = 10$ (5% damping) was assumed for the frog as well as for all of the structural modes.

The worst case for base excitations is case 3, the vernier thrusters with Marshall Space Flight Center data, resulting in a .027 Mg maximum acceleration at 28 Hz. The spinning case produces no response if it is perfectly balanced; however, accelerations will be produced depending on the amount of unbalance weight and the distance located radially from the hub. As can be seen from these results, however, the contribution of any reasonable unbalance has only a negligible effect on acceleration output for the transient analysis of the motor start up. If the response calculations are carried far enough until the full speed of ω is achieved, the response characteristics approach that of a steady state solution which may be calculated more simply from static loads. A steady state calculation of balancing weight requirements and allowable centrifuge imbalance follows in the next section.

Centrifuge Balancing

The VFR experiment requires that spurious acceleration inputs to the test specimen from auxiliary equipment and centrifuge unbalance excitations be limited to less than 0.001 g's. The purpose of the centrifuge balancing calculations were to determine the amount of centrifuge unbalance that could be tolerated and still satisfy the 0.001 g requirement, and to establish specimen canister, canister support assembly and centrifuge balancing weight requirements.

The analysis considered the "elastic" centrifuge support structure connected through a set of springs to a rigid base, as shown in Figure 39. If the rotor is unbalanced by a weight ΔW located on the outer rim as shown, a set of oscillating forces at frequency ω (radians/second) are exerted on the centrifuge assembly as the rotor turns. Axial and radial

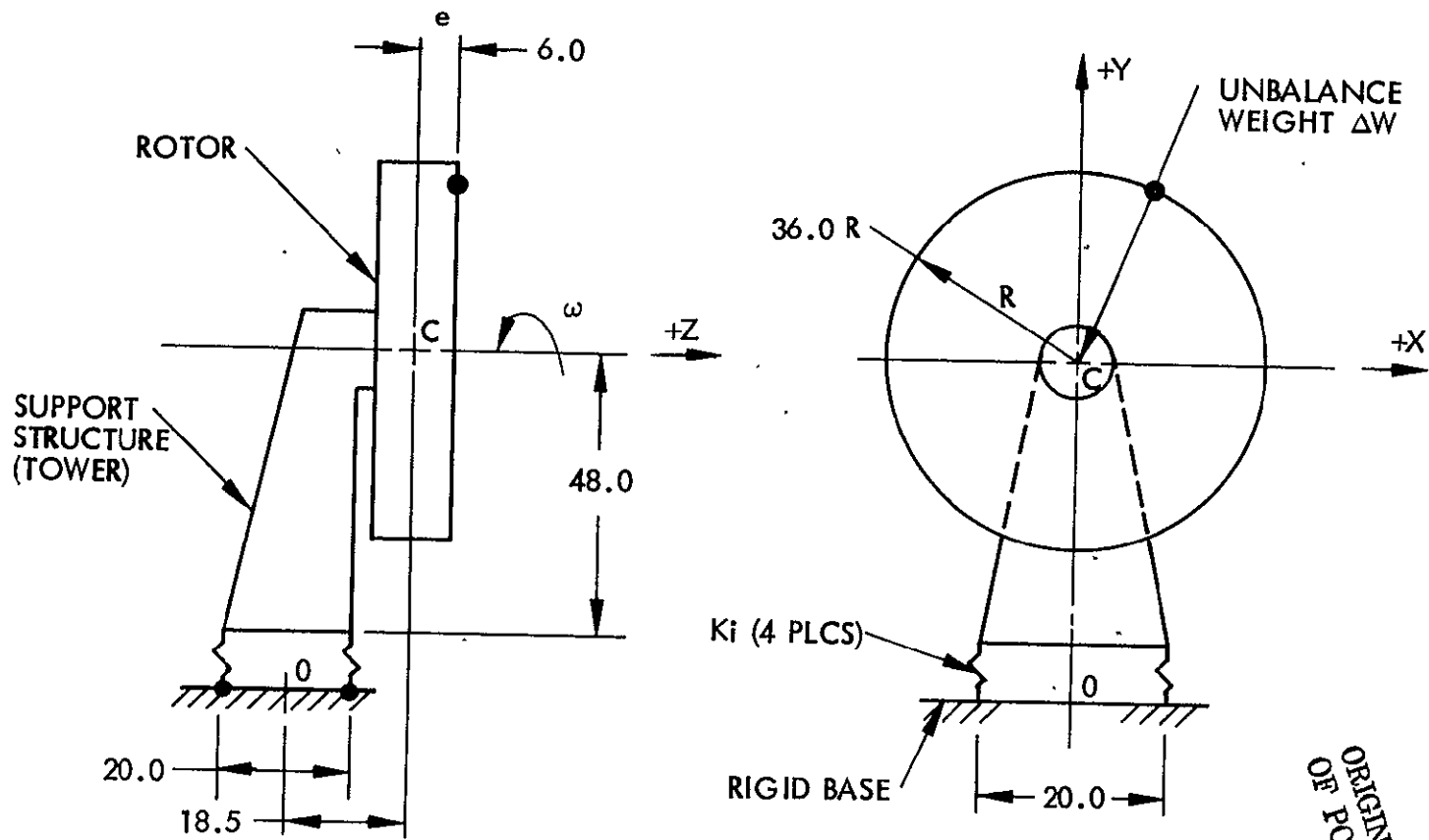


Figure 39 VFR Centrifuge Assembly

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runout of the centrifuge, relative to the drive motor mounting also imposes a set of oscillating forces on the assembly. These forces result in a sinusoidal deviation of the motion of a given point P from the intended circular path lying in the centrifuge plane. These deviations will be due to

- o rigid body deflection of the entire assembly relative to the base as a result of the assembly to base mounting flexibility,
- o elastic deflection of the support structure and centrifuge assembly.

Since these deflections are sinusoidal at a frequency ω corresponding to the centrifuge speed, they result in additional or spurious accelerations being imposed on the test specimens.

The elastic deflections induced by the centrifuge unbalance are amplified if the centrifuge assembly has vibrational resonant frequencies which are close to the centrifuge speed. However, the maximum speed of 33 rpm corresponds to frequency of 0.55 Hz, while the computed centrifuge assembly resonant frequencies are above 15 Hz. Therefore, the dynamic amplification effects can be neglected and the centrifuge assembly displacements computed on the basis of static analysis.

Assembly/Base Mount Flexibility

The four springs K_i in Figure 39, represent the interface mounting flexibility between the VFR centrifuge assembly and the laboratory module. Although exact information on the interface mounting structure is not available, it seems reasonable to assume that the centrifuge assembly mount frequency will be at least 15 Hz, and that the first mount mode will consist of rigid body rotation of the assembly about point O as shown in Figure 39. The equation for the mount frequency is then

$$f_o = \frac{1}{2\pi} \sqrt{\frac{400 K_i}{I_o/g}}$$

where

$$\begin{aligned} f_o &= \text{mount frequency, Hz} \\ K_i &= \text{mount spring stiffnesses, lbs/in.} \\ I_o &= \text{moment of inertia of centrifuge assembly about point 0} \\ g &= \text{gravitational constant, } 386.1 \text{ in/sec}^2 \end{aligned}$$

Taking $f_o = 15 \text{ Hz}$ and $I_o \approx 1.0886 \times 10^6 \text{ lb-in}^2$, it is found that $K_i = 62611 \text{ lbs/in.}$

The above calculation, while only approximate, gives a value for the interface mounting stiffness which can be used in subsequent calculations and which appears to be reasonable with respect to actual hardware.

Assembly Rigid Body Deflection

The forces and moments acting about the centrifuge center (C) due to the rotor unbalance ΔW and runout are

$$\begin{aligned} F_x &\leq [\Delta w R + W_{\text{rotor}} r] \omega^2/g \\ F_y &\leq [\Delta w R + W_{\text{rotor}} r] \omega^2/g \\ F_z &\leq [\Delta w \bar{U}_z + W_{\text{rotor}} \bar{U}_z] \omega^2/g \\ M_{x_c} &\leq [\Delta w R e + \Delta w R \bar{U}_z + I_{\text{rotor}} \bar{\Theta}] \omega^2/g \\ M_{y_c} &\leq [\Delta w R e + \Delta w R \bar{U}_z + I_{\text{rotor}} \bar{\Theta}] \omega^2/g \\ M_{z_c} &\leq 0 \end{aligned}$$

where

$$\begin{aligned} \Delta w &= \text{rotor unbalance weight, lbs.} \\ R &= \text{rotor unbalance weight radius, in.} \\ e &= \text{rotor unbalance weight moment arm, in.} \\ W_{\text{rotor}} &= \text{rotor weight, lbs.} \\ r &= \text{rotor radial runout } (\frac{1}{2}\text{TIR}), \text{ in} \end{aligned}$$

$$\begin{aligned}
I_{\text{rotor}} &= \text{rotor inertia about X axis, lb-in}^2 \\
\bar{U}_z &= \text{rotor axial runout } (\frac{1}{2} \text{ TIR}), \text{ in.} \\
\bar{\Theta} &= \text{rotor rotational runout (wobble, } \frac{1}{2} \text{ TIR), rad} \\
\omega &= \text{rotor rotational frequency, } 2\pi \times \text{rpm}/60, \\
&\quad \text{radian /sec} \\
g &= \text{gravitational constant, } 386 \text{ in/sec}^2
\end{aligned}$$

From the above forces and the mounting spring rates K_i , the maximum displacements of any point on the rotor rim are found to be

$$U_x = \left[\Delta w R + W_{\text{rotor}} r \right] \frac{(84)(48)\omega^2}{400 K_i g}$$

$$\begin{aligned}
U_y = \left[\Delta w R \left[\frac{100}{18.5} + 18.5 + e + \bar{U}_z \right] + W_{\text{rotor}} r \left[\frac{100}{18.5} + 18.5 \right] \right. \\
\left. + I_{\text{rotor}} \bar{\Theta} \right] \frac{18.5 \omega^2}{400 K_i g}
\end{aligned}$$

$$U_z = \left[\Delta w R \left[\frac{48\bar{U}_z}{R} + e + \bar{U}_z \right] + 49 W_{\text{rotor}} \bar{U}_z + I_{\text{rotor}} \bar{\Theta} \right] \frac{84 \omega^2}{400 K_i g}$$

Taking $R = 36.0$ in., $U_z = r \approx .002$ in., $W_{\text{rotor}} = 200$ lbs., $I_{\text{rotor}} = 2.592 \times 10^5$ lb-in², $\omega = 3.4558$ hz (33 rpm), $e = 6.0$ in., $\bar{\Theta} = .694 \times 10^{-4}$ rad (28" TIR), and $K_i = 62611$ lbs/in, the above expressions gives:

$$\begin{aligned}
U_x &\leq 1.992 \times 10^{-6} + 1.793 \times 10^{-4} \Delta w \text{ in.}, \\
U_y &\leq 4.110 \times 10^{-7} + 2.460 \times 10^{-5} \Delta w \text{ in.}, \\
U_z &\leq 3.858 \times 10^{-6} + 2.243 \times 10^{-5} \Delta w \text{ in.},
\end{aligned}$$

Since these displacements are sinuoidal at frequency ω , the corresponding accelerations are given by $\ddot{U}_i = \omega^2 U_i$. Thus,

$$\begin{aligned}\ddot{U}_x &\leq 6.161 \times 10^{-8} + 5.546 \times 10^{-6} \Delta w \text{ g's,} \\ \ddot{U}_y &\leq 1.271 \times 10^{-8} + 7.609 \times 10^{-7} \Delta w \text{ g's,} \\ \ddot{U}_z &\leq 1.193 \times 10^{-7} + 6.938 \times 10^{-7} \Delta w \text{ g's}\end{aligned}$$

are the maximum spurious accelerations induced on the test specimens due to the assembly rigid body motion relative to its base for a given unbalance Δw .

Assembly Elastic Deflection

The finite element computer math model of the VFR centrifuge assembly was used to compute the displacements on the centrifuge rim for unit loads and moments acting as 0° , 90° , 180° , and 270° around the rim as measured from the X axis, with the assembly rigidly fixed at the laboratory mounting interface ($K_i = \infty$). The results of these calculations gave

$$(U_{\text{radial}}/F_R \Delta w) \leq .239 \times 10^{-4} \text{ in/lb,}$$

$$(U_{\text{tan}}/F_R \Delta w) \leq .453 \times 10^{-4} \text{ in/lb,}$$

$$(U_z/F_R \Delta w) \leq .271 \times 10^{-4} \text{ in/lb,}$$

and

$$(U_{\text{radial}}/M_{\text{Re}} \Delta w) \leq .407 \times 10^{-5} \text{ in/in-lb,}$$

$$(U_{\text{tan}_o}/M_{\text{Re}} \Delta w) \leq .554 \times 10^{-5} \text{ in/in-lb,}$$

$$(U_z/M_{\text{Re}} \Delta w) \leq .201 \times 10^{-3} \text{ in/in-lb,}$$

where $F_R = R \Delta w \omega^2/g$
and $M_{\text{Re}} \Delta w = R e \Delta w \omega^2/g$

The above values for U_i do not represent the displacements at the rim from the unloaded condition, but rather the radial, tangential, and axial deviations of a point on the rim from the circular path that the point would follow if the centrifuge had not deformed. Substituting the values for R , e , ω^2 , and g as used previously, and converting the displacements to the corresponding acceleration values gives

$$\begin{aligned}\ddot{U}_{\text{radial}} &\leq 1.664 \times 10^{-6} \Delta w \text{ g's,} \\ \ddot{U}_{\text{tangential}} &\leq 2.705 \times 10^{-6} \Delta w \text{ g's,} \\ \text{and } \ddot{U}_z &\leq 4.247 \times 10^{-5} \Delta w \text{ g's}\end{aligned}$$

The above represents worst case values in that it was assumed that the induced accelerations due to the radial force and moment unbalance add directly.

An additional set of elastic displacements are imposed on the centrifuge rim as a result of the centrifuge runouts r , $\bar{U}_z$, and $\bar{\Theta}$. The displacements for a point force and moment acting at the rotor hub will be slightly smaller than those calculated for a point force and moment acting at the rotor rim. However, for the purpose of this analysis, it will be sufficiently accurate to use the values for a point force and moment acting on the centrifuge rim. Thus, the displacements induced at the centrifuge rim by the centrifuge runouts r , $\bar{U}_z$, and $\bar{\Theta}$ are

$$\begin{aligned}U'_{\text{radial}} &\leq (.259 \times 10^{-4} W_{\text{rotor}} * r + .407 \times 10^{-5} I_{\text{rotor}} \bar{\Theta}) \frac{\omega^2}{g} \text{ in,} \\ U'_{\text{tan}} &\leq (.453 \times 10^{-4} W_{\text{rotor}} r + .554 \times 10^{-5} I_{\text{rotor}} \bar{\Theta}) \frac{\omega^2}{g} \\ \text{and} \\ U'_z &\leq (.453 \times 10^{-4} W_{\text{rotor}} r + .554 \times 10^{-5} I_{\text{rotor}} \bar{\Theta} + .390 \times 10^{-3} W_{\text{rotor}} \\ &\quad \bar{U}_z) \frac{\omega^2}{g}\end{aligned}$$

*rotor is the centrifuge

Substituting for W_{rotor} , r , $\bar{U}_z$, $\bar{\Theta}$, ω , and g , and converting the displacements to the corresponding accelerations gives

$$\begin{aligned}\ddot{U}'_{\text{radial}} &\leq 7.995 \times 10^{-8} \text{ g's} \\ \ddot{U}'_{\text{tan}} &\leq 1.127 \times 10^{-7} \text{ g's} \\ \ddot{U}'_z &\leq 2.619 \times 10^{-7} \text{ g's}\end{aligned}$$

at a centrifuge speed of 33 rpm.

Combination of Induced Accelerations

The accelerations induced on the test specimens from the various effects of rotor unbalance and runout have been calculated as a function of rotor unbalance in the previous discussions. These various acceleration components must be combined to determine the total induced acceleration error on the test specimens.

The most conservative method of combining the acceleration components is to assume that all the radial, tangential, and axial components add directly in themselves, and then compute the resulting vector. In other words

$$\begin{aligned}\ddot{U}_{\text{rad}_{\text{tot}}} &\leq \ddot{U}_{\text{rad}_{\text{III}}} + \ddot{U}_{\text{rad}_{\text{IV}}} + \ddot{U}'_{\text{rad}_{\text{IV}}} \\ \ddot{U}_{\text{tan}_{\text{tot}}} &\leq \ddot{U}_{\text{tan}_{\text{III}}} + \ddot{U}_{\text{tan}_{\text{IV}}} + \ddot{U}'_{\text{tan}_{\text{IV}}} \\ \ddot{U}_{z_{\text{tot}}} &\leq \ddot{U}_{z_{\text{III}}} + \ddot{U}_{z_{\text{IV}}} + \ddot{U}'_{z_{\text{IV}}}\end{aligned}$$

$$\text{and } \ddot{U}_{\text{tot}} \leq \sqrt{\ddot{U}_{\text{rad}_{\text{tot}}}^2 + \ddot{U}_{\text{tan}_{\text{tot}}}^2 + \ddot{U}_{z_{\text{tot}}}^2}$$

Substituting the computed values for $\ddot{U}_{\text{rad}_{\text{I}}}$, etc. in the above equations gives

$$\begin{aligned}\ddot{U}_{\text{rad}_{\text{tot}}} &\leq 1.416 \times 10^{-7} + 7.210 \times 10^{-6} \Delta w \\ \ddot{U}_{\text{tan}_{\text{tot}}} &\leq 1.743 \times 10^{-7} + 8.251 \times 10^{-6} \Delta w \\ \ddot{U}_{\text{z}_{\text{tot}}} &\leq 3.812 \times 10^{-7} + 4.316 \times 10^{-5} \Delta w\end{aligned}$$

$$\text{and } \ddot{U}_{\text{tot}} \leq 4.453 \times 10^{-5} \Delta w$$

The experiment requires that the total spurious induced acceleration on the specimen shall be less than 0.001 g's. Since the $\ddot{U}_{\text{tot}}$ value computed above represents the single amplitude of a sine wave, then

$$2\ddot{U}_{\text{z}_{\text{tot}}} \leq \ddot{U}_{\text{allowable}}$$

Taking $\ddot{U}_{\text{allowable}} = 0.001 \text{ g's}$, then $\Delta w \leq 11.229 \text{ lbs.}$ unbalance at a radius of 36.0 inches and an out of plane moment arm of 6.0 inches.

Specimen Canister - Gimbal Assembly Weight Balance Analysis

The specimen canister assembly is gimballed relative to the centrifuge structure to allow for reorientation of the specimen both before and during the experiment sequence. If the center of gravity (c.g.) of the canister gimbal frame assembly shifts during specimen reorientation, it will modify the centrifuge balance and induce unwanted accelerations. To minimize these unwanted accelerations and reduce the load on the canister tilt torque motor, it is required that the canister gimbal assembly e.g. be located at the intersection of the two gimbal axes regardless of the canister and outer gimbal frame positions.

A detailed weight and balance analysis of the specimen canister and moveable portion of the gimbal frame was conducted. The results of the analysis are tabulated below

<u>Item</u>	<u>Weight</u>	<u>Center of Gravity</u>		
		<u>X</u>	<u>Y</u>	<u>Z</u>
Specimen Canister	20.3099 lbs	+0.002 in	+0.005 in	+0.160 in
Gimbal Frame (Moveable Portion Only)	4.631 lbs	-.596 in	-.227 in	-.512 in

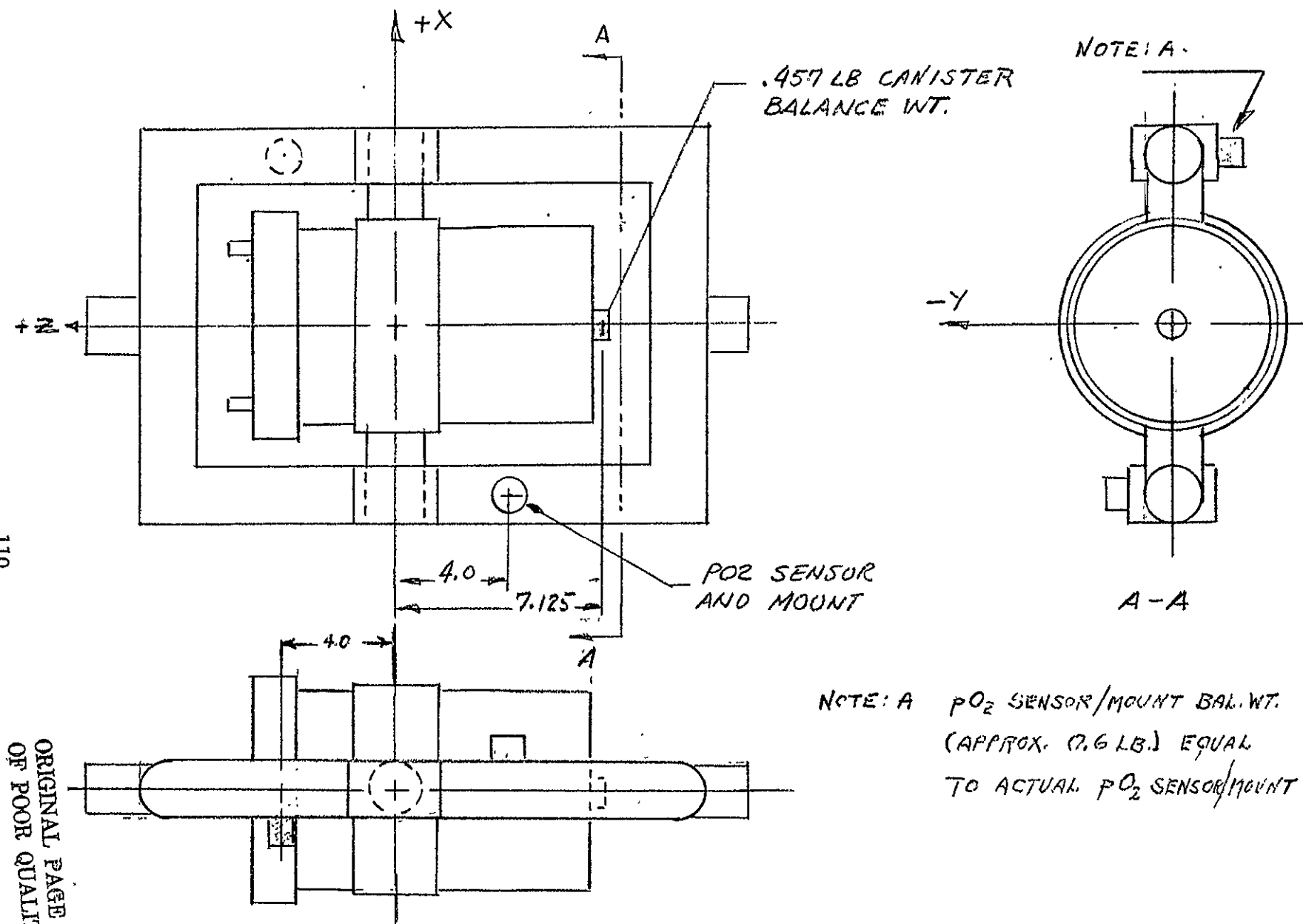
where the X, Y, Z axes are defined relative to the items in Figure 40. As a result of the analysis, the canister and gimbal designs were modified to incorporate two balancing weights, as shown by Figure 40, to bring the canister and gimbal assembly c.g. offsets to zero.

Centrifuge and Canister Control System

Figure 41 presents a simplified block diagram of the centrifuge and canister control system, which consists of a programmable microcomputer, electronic controller, centrifuge and canister torque motors and optical encoders. Also shown on Figure 41, are microcomputer control of the data system and interfaces with the Spacelab Remote Acquisition Unit. The microcomputer stores the 8 day mission profile providing scheduling of data system operation, centrifuge spin cycles, multiple spin cycles, steady "g" acceleration periods and equivalent spin cycles. The mission profile is executed by the main program which calls up subroutines that perform the scheduled events at the proper times. The subroutines provide binary words to the electronic controller for centrifuge speed and canister position. The controller acts on these rate and position signals to drive the centrifuge and canister torque motors. Optical encoders on each motor generate rate and position feedback signals that are used by the controller to adjust the error signal that drives the motors. The controller receives centrifuge speed and canister position words from the microcomputer and performs all motor control functions. The microcomputer outputs the speed and position words on a preprogrammed time basis to provide the needed accuracy of centrifuge speed and canister position.

For data system control, the microcomputer outputs binary words to configure the data system for recording or transmittal to the ground. Commands are received by the microcomputer from the RAU and the memory contents can be read out through the RAU. Canister position and centrifuge speed signals go directly to the data system from the controller and do not interface with the microcomputer.

110



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Figure 40 Canister & Gimbal Balance Weight Locations

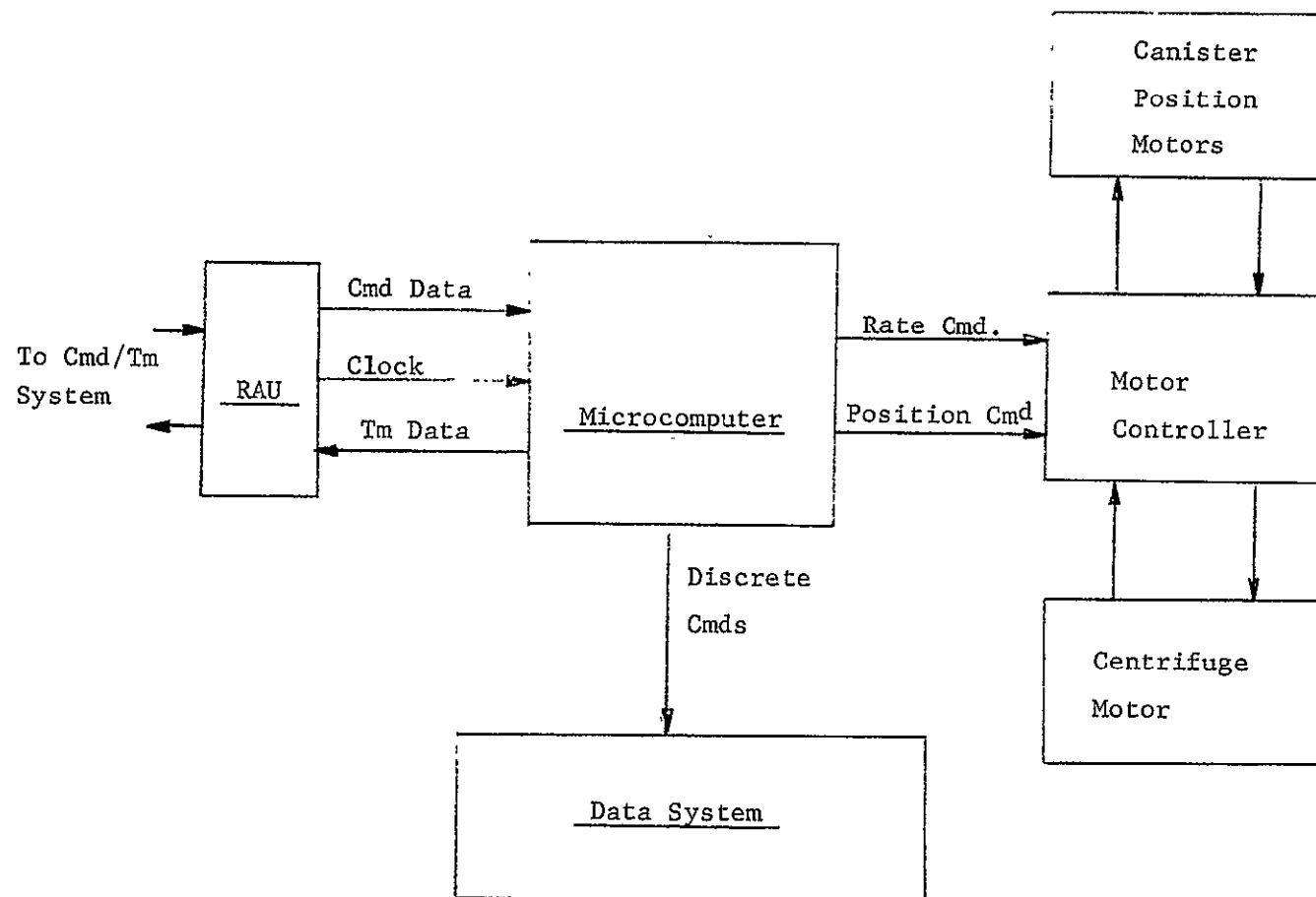


Figure 41 Experiment Control System

Control Requirements

The centrifuge angular rate is controlled by a rate servo over the range of 0 to 3.356 radians per second (0 to 1.05 g centrifugal acceleration). The four specimen canisters are positioned by a position servo over the range of 0 to 90 degrees. Both of these control servo systems operate in three modes:

- o Spin Cycle

The centrifugal acceleration is increased linearly from 0 to 0.3 g in 8 seconds, held at 0.3 g for 60 seconds and decreased linearly from 0.3 to 0 g in 14 seconds. Linearity of the ramp up and ramp down is within ± 0.01 g. The canister angle is held at zero degrees.

- o Adjustable Centrifugal Acceleration

The centrifuge is capable of producing any steady state centrifugal acceleration in 0.05 increments over the range of 0 to 1.0 g. Prior to starting this mode, the canisters are rotated to 90 degrees and held at 90 degrees.

- o Equivalent Spin Cycle

Initially, this operating mode is the same as the adjustable Centrifugal Acceleration mode. Once the selected steady state centrifugal acceleration (g_0) has been reached, the centrifugal acceleration is increased and the canister is tilted, to produce an equivalent g vector on the canister that the spin cycle would produce if the canister were at zero degrees with a constant acceleration (g_0) in the direction of the centrifuge axis.

Servo System Description

A block diagram of the centrifuge and canister motion control system is shown in Figure 42. The microcomputer provides an 11 bit programmed command to the centrifuge servo and an 8 bit programmed command to the four canister servos. A +5V regulator provides power to the T^2L type digital integrated circuits and a DC to DC converter supplies $\pm 10V$ to the operational amplifiers. All five control loops are based on the BEI Electronics ULTRA-LOCTM control system which is a feedback loop technique utilizing an optical encoder mounted on the motor shaft as a rate or position transducer. Rate which is proportional to the simulated gravity level is the centrifuge controlling function while position is the canister controlling function.

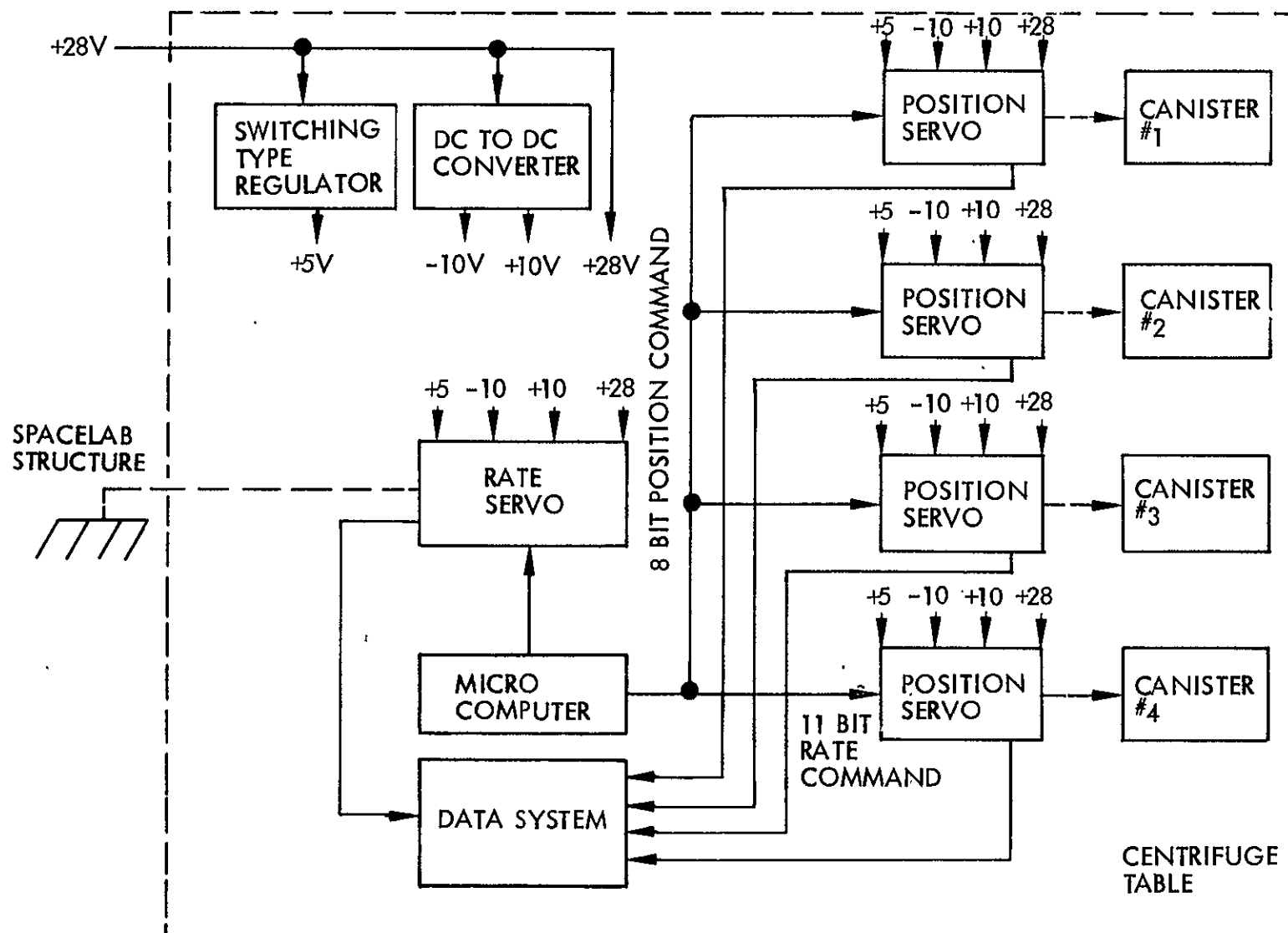


Figure 42 Centrifuge and Canister Servo System

Centrifuge Rate Servo

Figure 43a presents a more detailed block diagram of the centrifuge rate servo. In operation the binary code word representing angular rates from 0 to 3.356 radians per second "commands" the rate desired. This code word is applied to the programmable frequency generator which produces a single output signal (R) having the frequency (f_R), where $f_R = f_g + mf$. The integer m is equivalent to the integer value of the input code word and f_g is the frequency increment. For example, if the input ω code word is 00000101001 then $f_R = f_g + 41 f$. The frequency generator output is fed into the frequency phase comparator which also receives signals from the optical resolver on the centrifuge torque motor. A phase variable signal (PV) having a frequency $f_{pv} = f_o + f_{pc}$ is generated by the optical resolver. Frequency f_{pc} represents the encoder photocell frequency and varies linearly with rate. It is a positive value for clockwise rotation and a negative value for counterclockwise rotation.

The two input signals of the frequency phase comparator are compared to produce an error signal which varies from a negative to a positive maximum for 360 degrees of phase change between signals (R) and (PV). This phase change corresponds to a shaft angle change of one disk pattern cycle, i.e., one blank line plus one clear aperture. Thus, as disk resolution increases the torque per arcsecond (stiffness) increases.

The phase comparator output error signal is applied to the servo control compensation networks which are made up of several operation amplifiers that determine the loop characteristics such as response time, overshoot, etc. The output signal from the compensation networks is applied to the motor drive circuit which amplifies the low-level control circuit signals to a level compatible with the motor. As the motor moves, the optical resolver generates a new signal PV, which is fed back to the comparator completing the feedback loop.

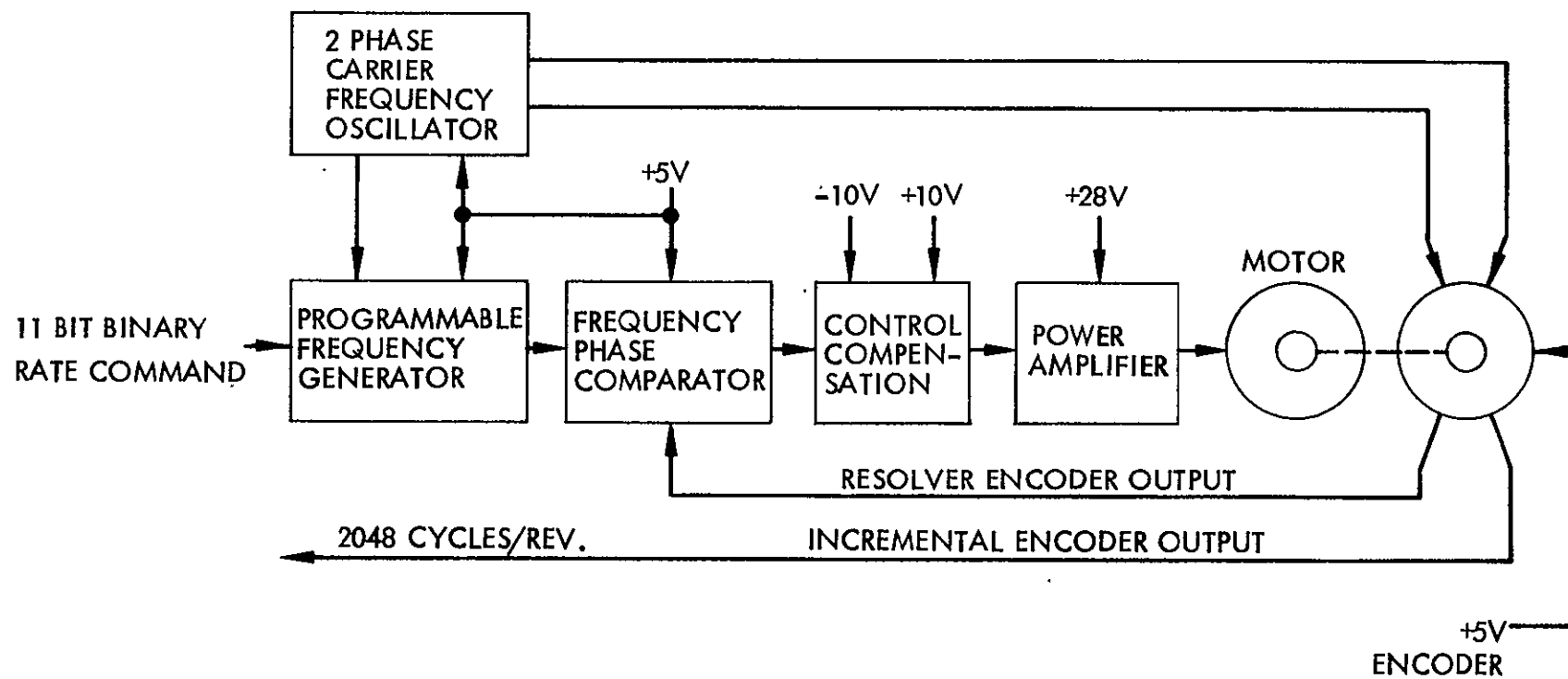


Figure 43a Centrifuge Rate Servo

Canister Position Servo

The block diagram of the canister servo is shown by Figure 43b. The position servo contains an inner rate loop and an outer position loop. The feedback device for the position loop is an absolute angle position encoder. An 8 bit position code word, representing 0 to 90°, is applied to command the canister to rotate to an equivalent computer position. The code disk of the shaft angular encoders is coded in cyclic gray code. This code has the characteristic that only one of the eight output lines undergoes a change in binary state at any one angular position. The gray code is converted to natural binary code and then compared to the position command word. The output code of the "Position Error Logic" blocks is a signed difference of the position command and the actual sensed position. This code is further converted to form rate code commands. In general, if the angular difference between the commanded position and sensed position is large, then the rate code is large and the encoder moves rapidly toward its destination. As the positional difference diminishes the rate code diminishes in a non-linear relationship. This method reduces the positional overshoot upon arrival to a minimum value.

System Characteristics

The centrifuge and canister control system have the following characteristics:

- o The torque motors are direct drive, permanent magnet DC torquers with brushes.
- o The power amplifiers that energize the motors are linear type, direct current with current controlled output.
- o T²L type integrated circuits are used for all digital circuits.
- o The control compensation circuitry utilizes two or three operational amplifiers to provide a transfer function of
$$\frac{K(Z_1S+1)}{Z_2S+1}$$
- o The optical encoder for the centrifuge contains a 8192 cycles/revolution resolver encoder and an 2048 cycles/revolution incremental encoder.

117

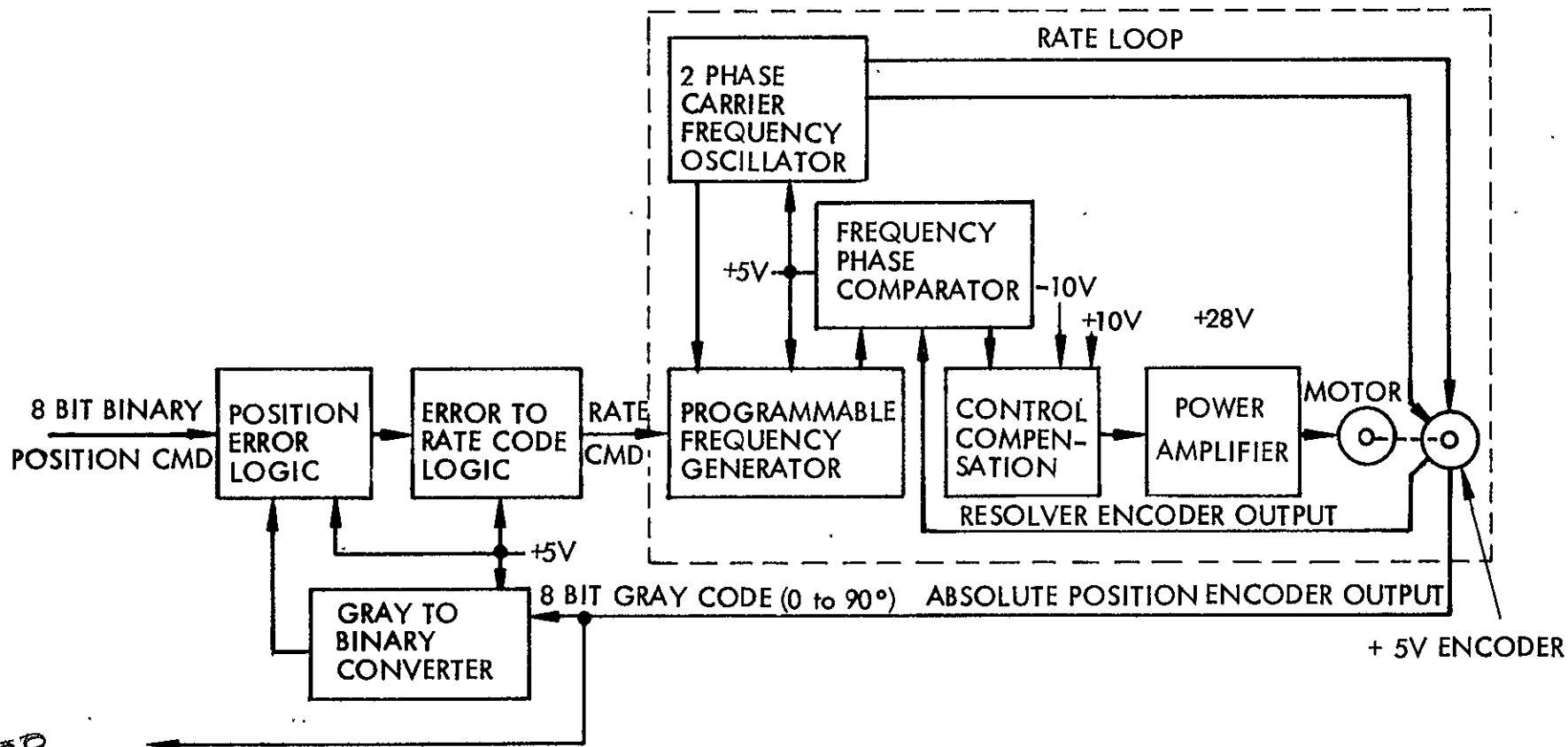


Figure 43b Canister Position Servo Block Diagram

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- o The two phase carrier frequency oscillator, programmable frequency generator and frequency/phase comparator for the centrifuge control consist of approximately fifteen digital integrated circuits.
- o The optical encoders for the canisters each contain a 512 cycles/revolution resolver encoder and an 8 bit absolute position encoder for a 90° revolution.
- o The gray to binary converter, position error logic, position error to rate command, two phase carrier frequency oscillator, programmable frequency generator and frequency/phase comparator for each canister control consist of approximately twenty digital integrated circuits.

Centrifuge Torque Motor Sizing

The centrifuge torque motor size is determined by the initial startup from zero speed, during a spin cycle, where it is required to maintain as close as possible linearity of centrifuge acceleration with time. A deviation from linearity of 0.01 g is allowable. The centrifuge torque motor size required to meet experiment requirements was determined in the following manner.

Centrifuge angular velocity (ω) is related to linear acceleration (g) and centrifuge radius (R) by:

$$\omega = \sqrt{\frac{32.2 \text{ g}}{R}} \quad (1)$$

During the spin up of a spin cycle, g must increase linearly from 0 to 0.3 in the first eight seconds. Therefore

$$g = st \quad (2)$$

where: t = time in seconds and s is a constant = 0.3/8

Substituting equation (2) into (1) gives:

$$\omega = \sqrt{\frac{32.2 \text{ st}}{R}} \quad (3)$$

Centrifuge angular acceleration (α) is the rate of change of angular velocity (ω) with time. In differential form

$$\alpha = \frac{d\omega}{dt} \quad (4)$$

Taking the derivative of (3) and substituting into (4) gives:

$$\alpha = \frac{1}{2\sqrt{\frac{Rt}{as}}} \quad (5)$$

Equation (5) shows that when time equals zero, the angular acceleration (α) must be infinite to achieve linearity. Since motor torque is $T = J\alpha$, where J is the moment of inertia, an infinite torque is also required. Figure 44 presents a plot of equation 5, graphically presenting the angular acceleration and torque requirements. The moment of inertia of the rotating portion of the centrifuge design presented by Figure 31 was calculated to be 34.3 lb-ft-sec².

To select a practical torque motor size, the allowable deviation of 0.01 g must be considered.

A torque motor must be sized to accelerate the centrifuge at a rapid enough rate, so that no more than 0.01 g error builds-up before the motor torque equals the required torque presented by Figure 44. Figure 45 presents the results of a calculation that established a torque of 21.06 ft-lbs was required. With such a torque the centrifuge acceleration will lag behind the desired linear curve for 0.533 seconds. From 0.533 seconds until 1.066 seconds, motor torque exceeds that required for linearity, so the error decreases until at 1.066 seconds zero error exists. The following equations were developed to size the centrifuge torque motor.

If a rate command is applied to the control system at $t = 0$, the motor torque will be a maximum until the rotor is accelerated (at a constant value) to the desired angular velocity (ω).

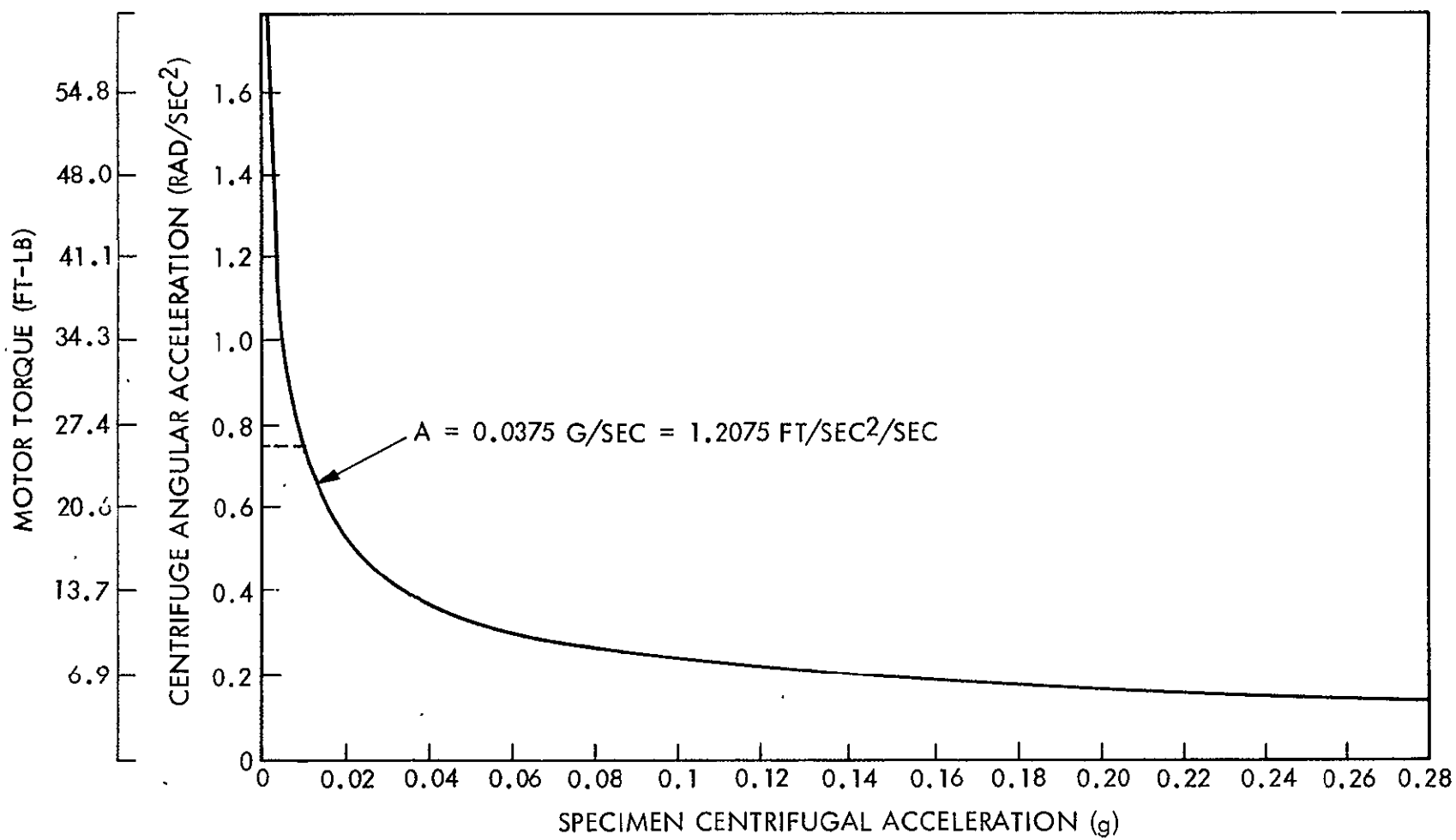


Figure 44 Angular Acceleration and Motor Torque Required for Linearly Increasing g During Centrifuge Spinup

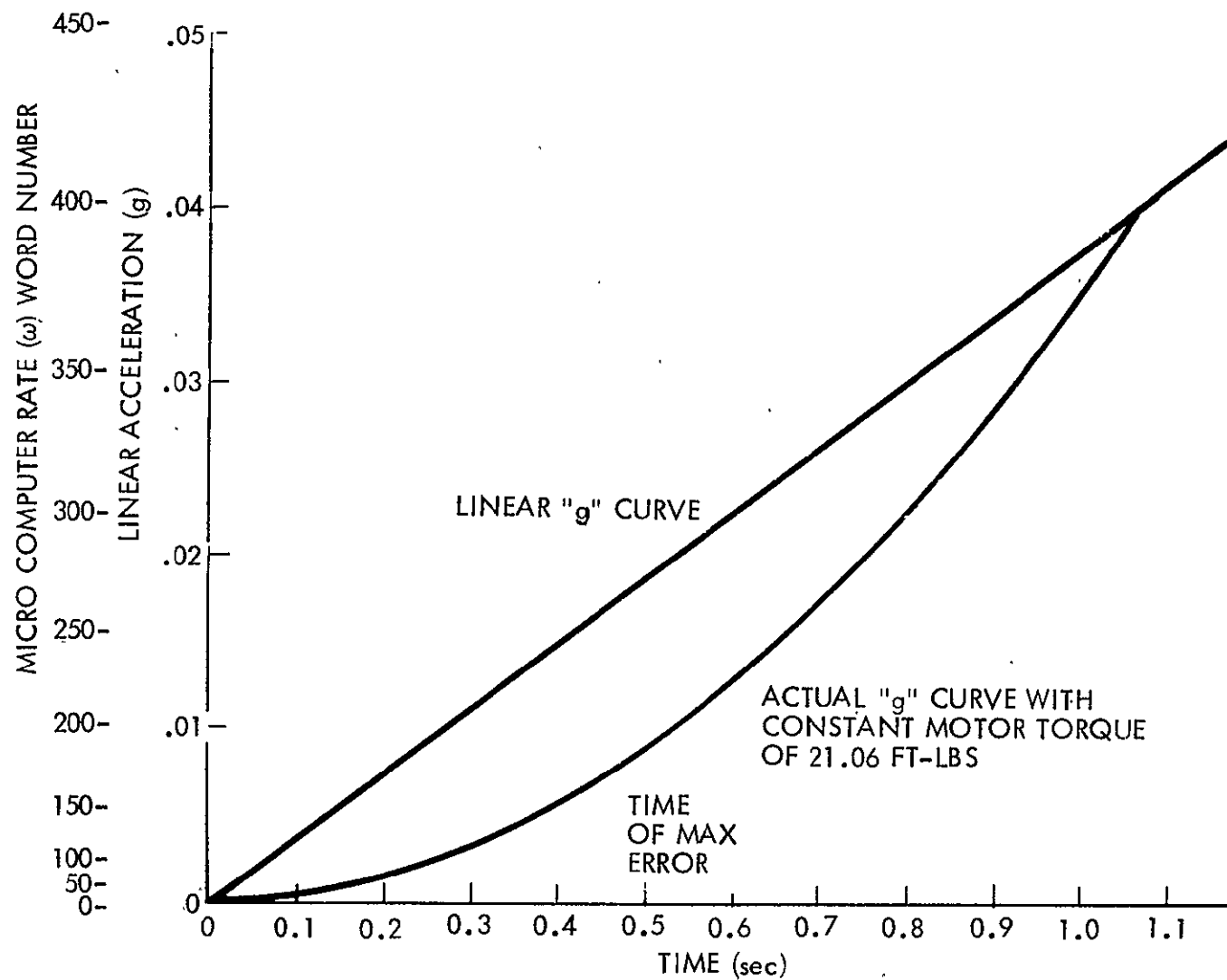


Figure 45 Centrifuge Linear Acceleration vs Time for Ideal and Actual Case

The angular velocity (ω) in this first time interval is given by:

$$\omega = \alpha t \quad (6)$$

Consequently the g value in this first interval (g_1) is found by substituting equation (6) into (1) yielding:

$$g_1 = \frac{R (\alpha t)^2}{32.2} \quad (7)$$

The error (ξ) in g value is found by:

$$\xi = g - g_1 \quad (8)$$

Substituting equations (2) and (7) into (8)

$$\xi = st - \frac{R(\alpha t)^2}{32.2} \quad (9)$$

At the time $t = t_A$, the error (ξ) is 0 and the accelerating rotor has "caught-up" with the ideal g-value determined by $g = st$. From Equation (9) and $\xi = 0$,

$$t_A = \frac{32.2S}{R\alpha^2} \quad (10)$$

At some point of time between $t=0$ and $t=t_A$, the error ξ reaches a maximum value. In the following analysis, a relationship for a maximum ξ is first determined and then set equal to the maximum allowable error value (.01). From this, a minimum acceleration is determined. Replace t by Kt_A in Equation (9) and get:

$$\xi = Kst_A - \frac{R(\alpha Kt_A)^2}{32.2} \quad (11)$$

Taking a deviative with respect to K yields:

$$\frac{d\xi}{dK} = st_A - \frac{2R\alpha^2 Kt_A^2}{32.2} \quad (12)$$

Substitute $\frac{R\alpha^2}{32.2} = \frac{s}{t_A}$ from Equation (10) into Equation (12) to get:

$$\frac{d\epsilon}{dK} = st_A - 2K St_A$$

When $\frac{d\epsilon}{dK} = 0$, $K = \frac{1}{2}$. A maximum error ($\epsilon_{\max}$) thus occurs when $t = \frac{1}{2}t_A$.

The value of $\epsilon_{\max}$ is determined by substituting $K = \frac{1}{2}$ into Equation (11):

$$\epsilon_{\max} = \frac{St_A}{2} - \frac{R\alpha^2 t_A}{128.8} \quad (13)$$

Substituting $\frac{R\alpha^2}{32.2} = \frac{s}{t_A}$ from Equation (10) into Equation (13) yields:

$$\epsilon_{\max} = \frac{St_A}{4} \quad (14)$$

When $\epsilon_{\max} = 0.01$ and $S = .0375$, the "catch-up" time $t_A = \frac{.04}{.0375} = 1.066$ seconds.

The maximum error in g - value occurs at one half of t_A or .533 seconds.

The acceleration required to "catch-up" is found by rearranging (10) so that:

$$\alpha = \frac{32.2S}{Rt_A} \quad (15)$$

For $t_A = 1.066$, $R = 3$, and $s = .0375$, the required acceleration $\alpha = 0.614$.

For $J = 34.3 \text{ lb-ft-sec}^2$, the motor torque to produce $\alpha = 0.614$ is 21.06 lb-ft.

A motor larger than this required size has been selected and has the following characteristics:

Peak Torque	25 lb-ft
Torque Constant	3.85 lb-ft/amp
Winding Resistance	3.2 ohms
Back EMF Constant	5.5 volts/rad/sec

The linear type power amplifier requires an output current range of $\pm 25/3.85 = \pm 6.5$ amps.

This torque motor will meet all other centrifuge motion requirements and will be controlled by the centrifuge electronic controller that is commanded by angular rate words fed to it by the microcomputer.

Canister Torque Motor Sizing

Canister tilting is required to accomplish steady state acceleration profiles and the equivalent spin cycles. The latter size the canister torque motors, because a fast positioning rate prior to steady "g" profiles is not required.

In the equivalent spin cycle, the frog is first rotated to a canister position $\theta = \pi/2$ radians when $t = 0$. The centrifuge is then rotating at a steady g-value (g_s) that is equal to the steady g-value to be simulated. When the equivalent spin cycle begins, the centrifuge increases its rotation rate to simulate the magnitude of the combined steady g plus the vector sum of 0 to 0.3 g. Thus :

$$g_e = \sqrt{g_s^2 + (St)^2}, \quad (16)$$

where S is the slope of the g versus time curve. The quantity g_s can be any multiple of .05 from 0 to 1.0, the value (st) is between 0 and 0.3.

Canister angular position (θ) must change so that the direction of the g_e vector relative to the frog is the same in the equivalent spin cycle as it is in a normal spin cycle. Ideally, angular position (θ) of the frog and canister is given by:

$$\theta = \frac{\pi}{2} - \tan^{-1} \left(\frac{St}{g_s} \right) \quad (17)$$

Figure 46 presents a plot of the canister angle versus time that is required to produce the ideal equivalent spin cycle motion for steady g_s values of 0.05, 0.3, 0.5, and 1.0.

Taking the first derivative of θ with respect to time in equation (17) yields an expression for canister angular velocity (ω_F) i.e.

$$\omega_F = \frac{d\theta}{dt}$$

$$\omega_F = - \frac{Sg_s}{(g_s)^2 + (St)^2} \quad (18)$$

At time $t = 0^+$, $\omega_F = S/g_s$ whereas at time $t = 0^-$, $\omega_F = 0$. This indicates a step change requirement in angular velocity at $t = 0$. It also indicates a need for infinite acceleration and infinite motor torque at time $t=0$. The inset on Figure 46 presents the values of S/g_s for g_s values of 0.05, 0.3, 0.5 and 1.0. The need for infinite acceleration at $t=0$ to meet the ideal curve means that errors will result from the use of a reasonable torque motor size. In order to determine error versus torque motor size, the data presented by Figure 47 was generated using the following equations:

$$\alpha = \frac{T}{J} \quad (19)$$

where:

T = motor torque (ft-lbs)

J = moment of inertia of moving canister assembly (slug-ft²)

α = angular acceleration (radians/sec)

and:

$$\theta = \frac{1}{2} \alpha t^2 \quad (20)$$

where:

θ = canister angular displacement (degrees)

t = time (seconds)

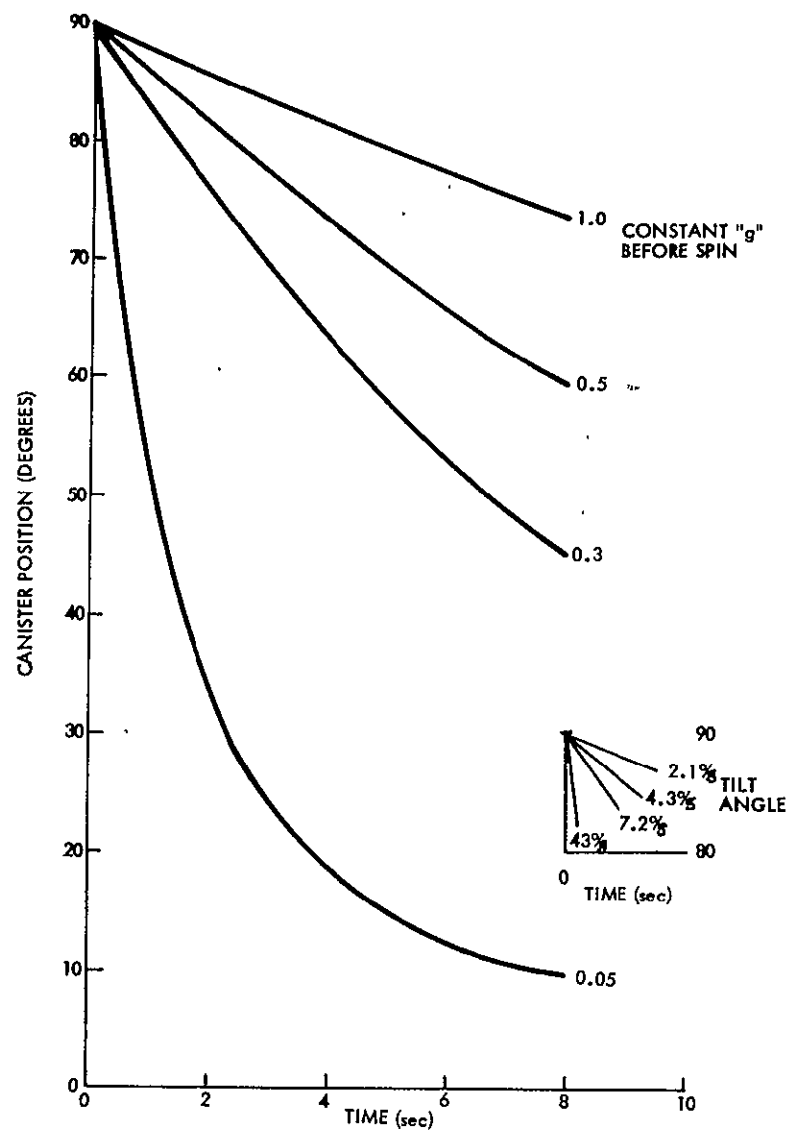


Figure 46 Canister Tilt Angle vs Time for Equivalent Spin Cycle

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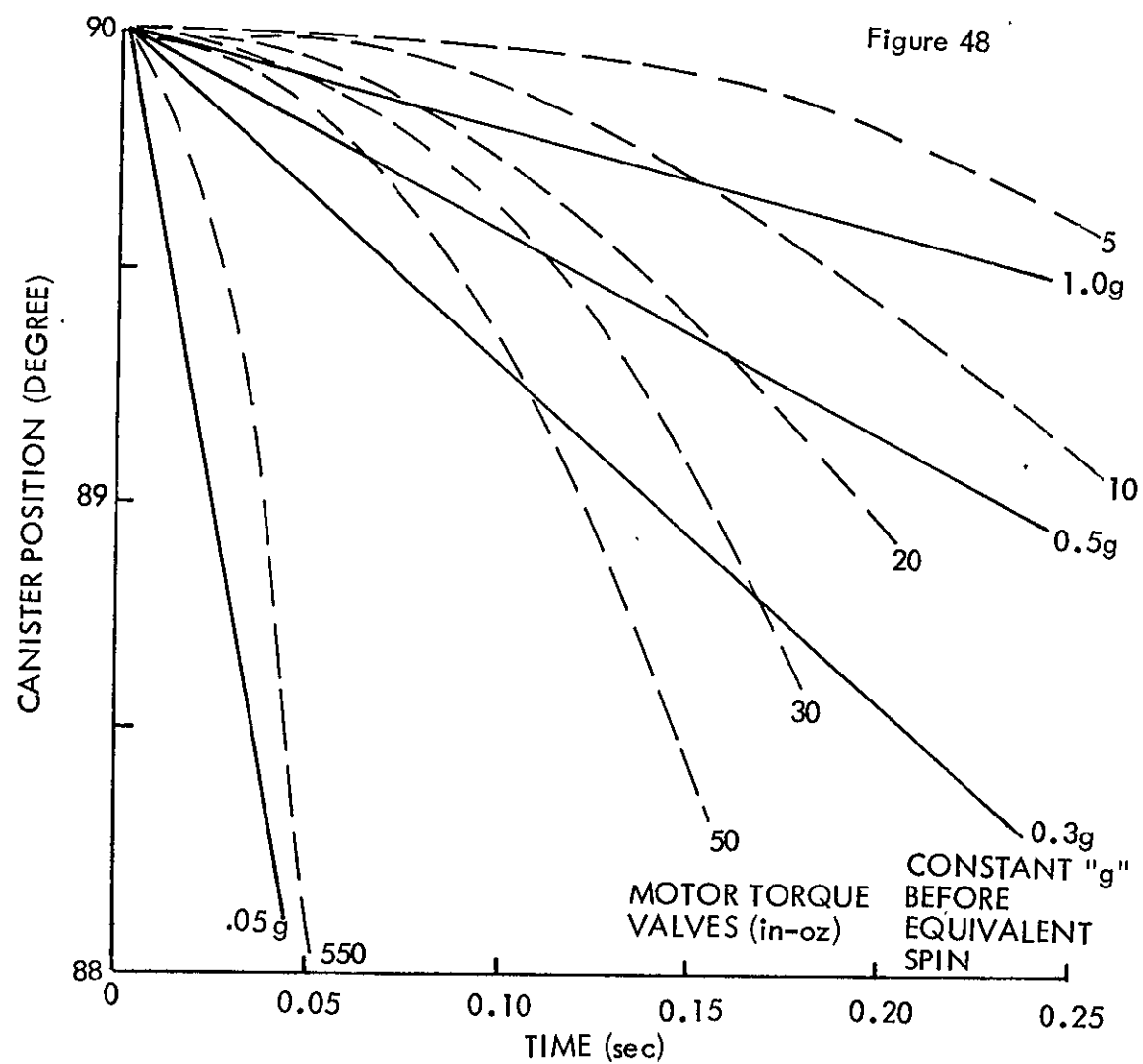


Figure 47 Required Canister Tilt vs Torque Motor Capabilities

For an assumed torque valve and known J of the canister assembly (0.109 slug-ft^2), the resultant α can be calculated. From the known α , Θ values can be calculated as a function of time and compared with required Θ angles from equation 17. Figure 48 is the result of such a calculation. Position error for each assumed motor torque was cross plotted to develop required motor torque vs position error. Figure 48 presents the final results. Inspection of Figure 48 shows that motor torques becomes excessive at steady "g" values in the range of 0 to 0.3 g. Motor torques of 50 in-oz result in reasonable power consumption and size. This means that position errors less than 0.5 degrees can be achieved for equivalent spin cycles that start from steady "g" values from 0.3 to 1.0. The experiment requirements provided that for steady "g" values for 0 to 0.3 g's the canisters can be positioned to the final Θ prior to beginning the equivalent spin cycle. This not only reduces torque motor size, but also simplifies the storage of position commands in the microprocessor. The analysis led to a selection of 50 in-oz as a canister motor design torque.

The preceding analysis assumes that it is desirable to follow the linear spin cycle "g" vs time line of 0 to 0.3 g in 8 seconds. As previously pointed out the centrifuge does not follow this ideal curve, but lags behind it in the first 1.066 seconds. If the actual centrifuge "g" curve is followed for the equivalent spin cycle, motor torque requirements can be greatly reduced. The required canister angular position to follow the actual centrifuge "g" curves is given by:

$$\Theta = \frac{\pi}{2} - \tan^{-1} \left(\frac{R\alpha^2 t^2}{32.2 g_s} \right) \quad (21)$$

for the first 1.066 seconds.

The first derivative of Equation 21 yields the angular velocity

(ω_F) where

$$\omega_F = - \frac{2R\alpha^2 t}{(32.2 g_s)^2 + (R\alpha^2 t^2)^2} \quad (22)$$

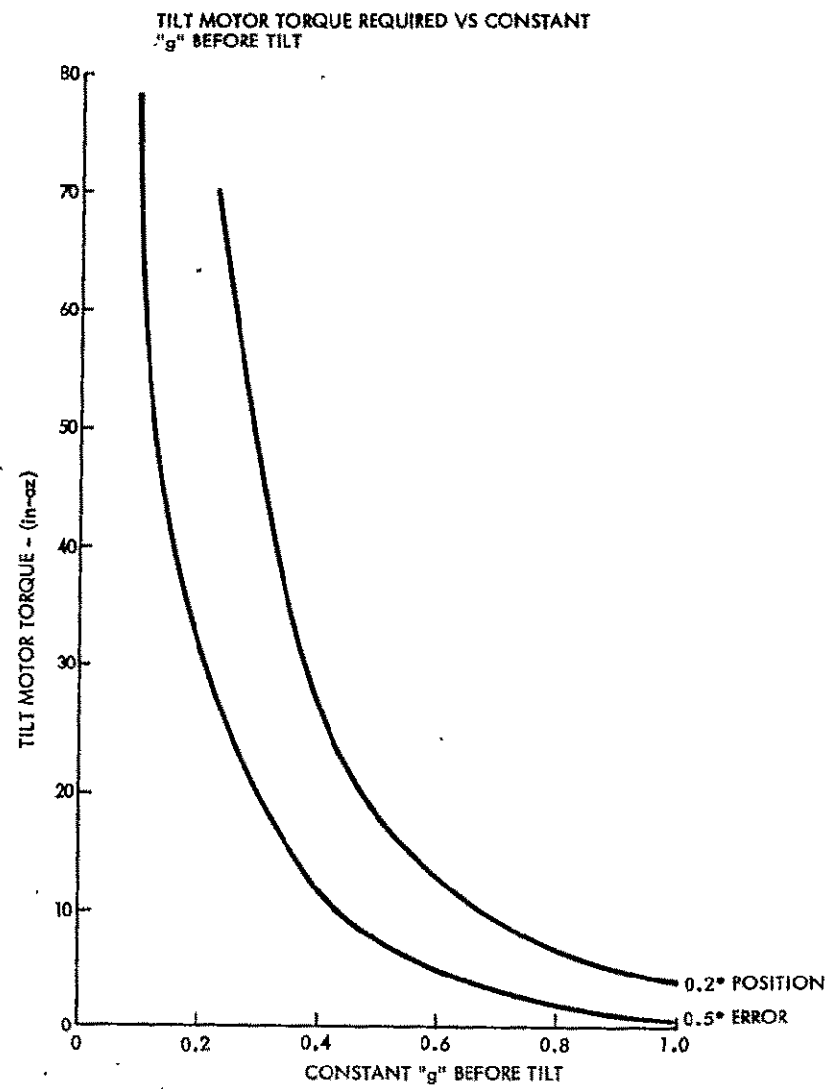


Figure 48 Tilt Motor Torque Required vs Constant "G" Before Tilt

where α = centrifuge acceleration during the non-linear spin-up in the first 1.066 seconds of a spin cycle.

The largest acceleration requirement occurs when the equivalent spin cycle is simulating the lowest steady g values. For g values less than 0.3, the specification allows the canister to be moved to its final position prior to the equivalent spin cycle.

Thus, an equivalent spin cycle for the steady g of 0.3 is the torque determining case. Initial acceleration is determined by differentiating Equation 22 and substituting $t = 0$. This process yields.

$$\alpha_o = \frac{2R^2}{32.2 g_s} = \frac{2(3) (.614)^2}{(32.2) (0.3)} \quad (23)$$

$$\alpha_o = 0.234 \text{ radians/sec}^2$$

Using a value of 0.109 lb-ft second² for canister moment of inertia (J_c) the initial torque (T_c) required is $T_c = J\alpha = 0.109 (0.234) = .026$ lb-ft or 4.9 oz-inches. This low value is comparable to bearing friction values. A higher torque value would have to be selected to avoid erratic torque output caused by the non-linear friction.

The selected motor has the following characteristics:

Peak Torque	50 oz-inches
Torque Constant	90 oz-in/amp
Winding Resistance	38 ohms
Back EMF Constant	0.64 volts/rad/sec

The dc, linear power amplifier has an output current range of $\frac{50}{90} = \pm 0.56$ amperes.

Experiment Microcomputer

The experiment microcomputer (MC) serves as the central controller for the VFR experiment. The MC controls the centrifuge rate and canister positions using stored profiles in accordance with a timetable which may be altered at any time by the operator. It also provides the interface between systems commands and the data system. The MC is based on the 1802 microprocessor. The 1802 is well suited to this application, because of its table lookup orientation. An experiment control system block diagram, including the MC, has been presented as part of the centrifuge control discussion in Figure 41.

The general requirements for the MC are as follows:

- o Maintain an Experiment Clock
- o Output Commands (centrifuge rate, canister position, data system) singly or in a programmed sequence at programmable times.
- o Input Systems Commands which include:
 - Addition or deletion of any event.
 - Clock Preset.
 - Memory Content Dump.
- o Output Clock Value continuously.

Software Design

Figure 49 presents a simplified flow chart of the microcomputer program. It can be divided into two parts, a prelaunch part of the program performs the duties required by the experiment after power-on but prior to launch. The main program controls the experiment operation and is by far the more complex.

Prelaunch Program

A flow chart of the prelaunch program is presented by Figure 50. The experiment requirements during this time are quite simple: every 4 hours (approximately) the data system must be turned on for 15 minutes. Also

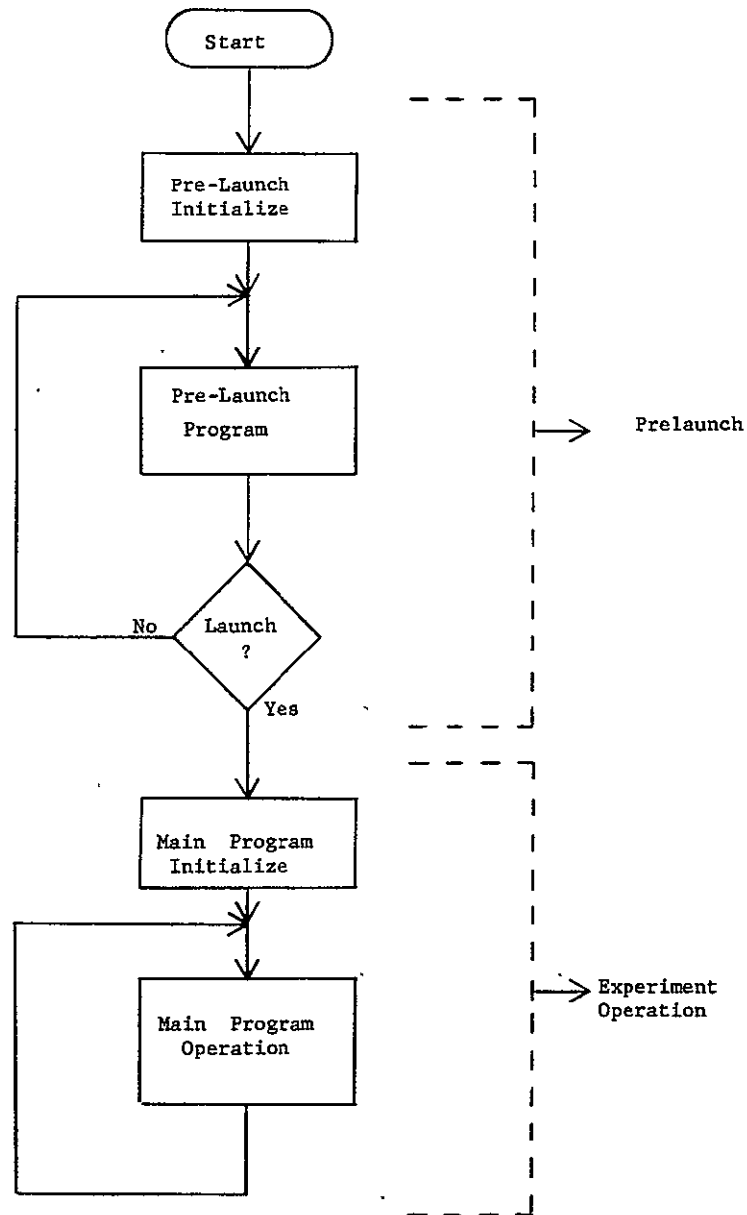


Figure 49 Program Flowchart

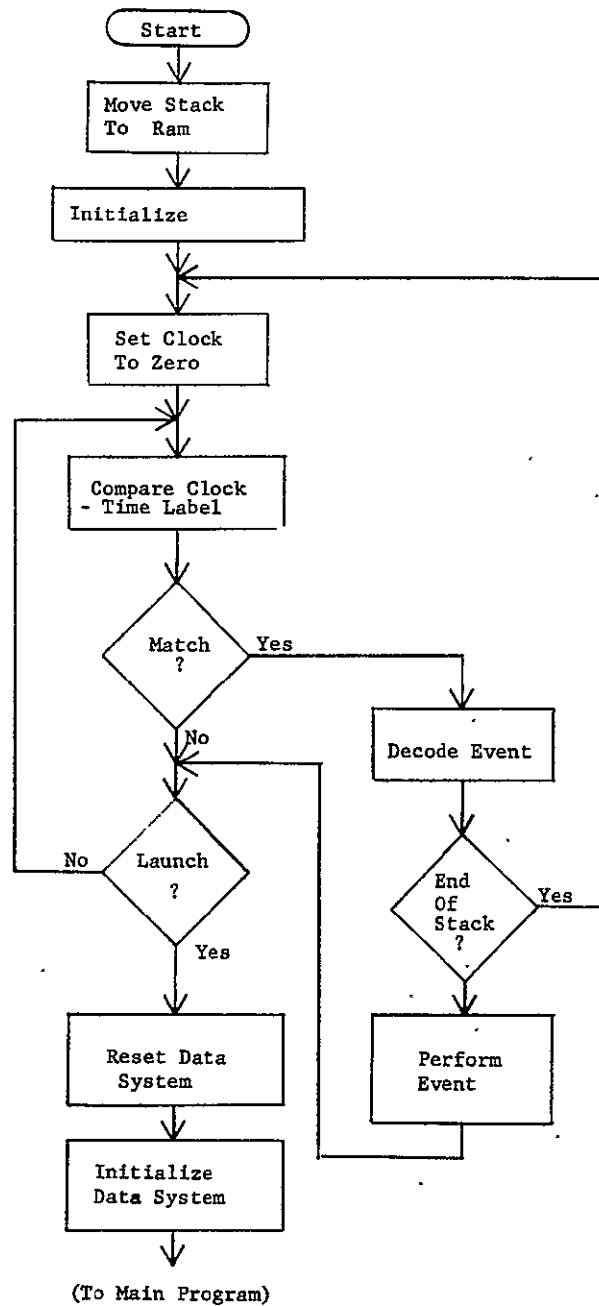


Figure 50 Prelaunch Program Flowchart

every 12 hours the wash pump must be activated for 20 minutes. These events are repeated until a launch signal is received by the micro-computer.

The approach to implementing these functions is also used in the main program and so are described here in some detail.

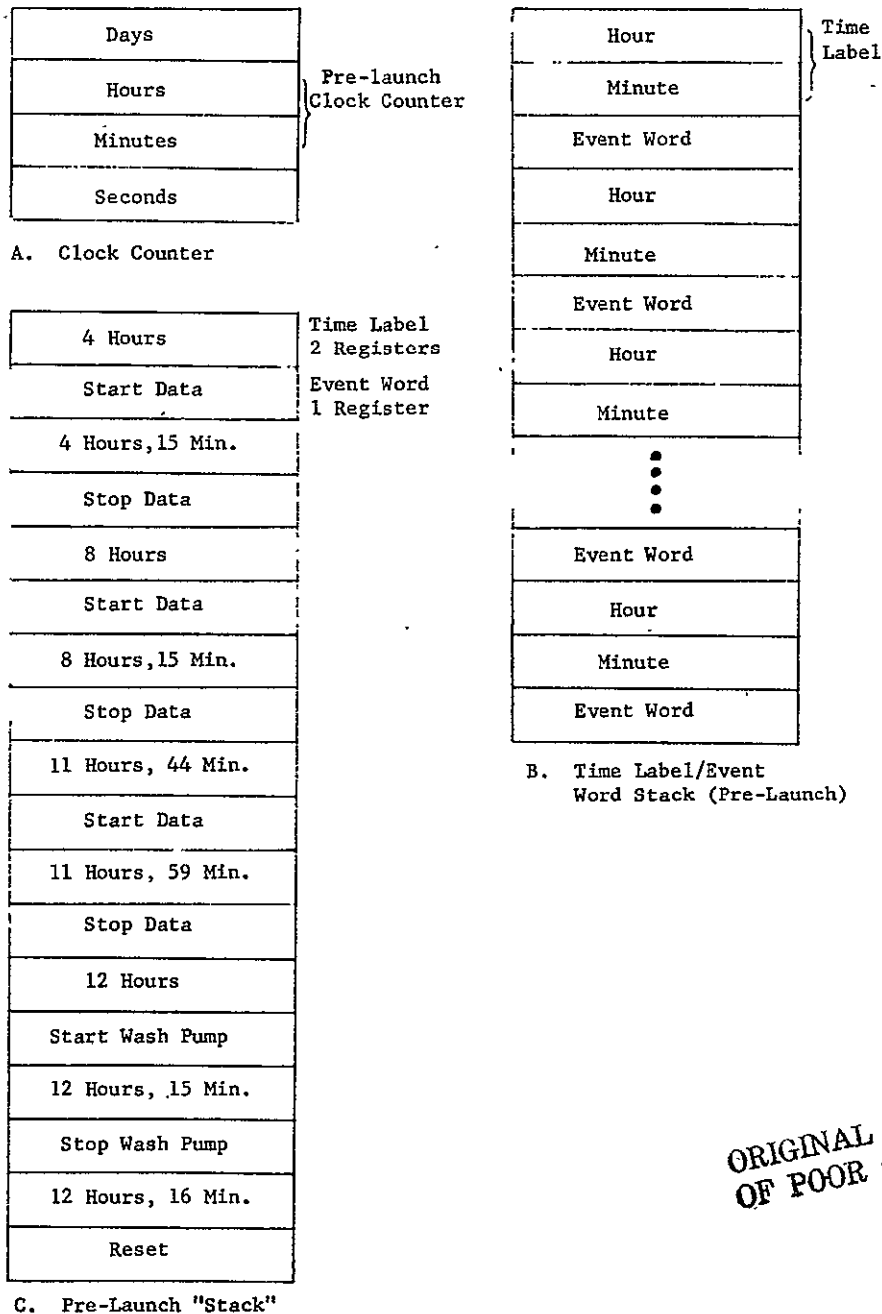
Programmed Event Generation

To describe the method used to output the event signals at the correct time, it is necessary to first describe the two main elements of the process.

The first element is the clock counter, which provides the time base for all events both prelaunch and postlaunch. The clock counter is derived from the microcomputer clock oscillator. The oscillator frequency, 2.048 MHz, is divided down, using external hardware to 1Hz, which is connected to the microprocessor interrupt line. The interrupt software is designed to increment the clock counter every second and so the clock counter functions as a very accurate time base. The clock counter is maintained in read/write memory (RAM) in BCD format using four registers as shown in Figure 51A.

The second element is the time/event stack, which for the prelaunch program, is stored in read-only memory (RAM). This stack is made up of a series of time labels and event codes as shown in Figure 51B.

Combining both elements results in a simple flexible way to produce an event versus time function. To do this the program compares the clock counter with the first time label and continues to do so until either a match occurs or a launch signal occurs. If a match occurs the associated event code is decoded and the required action is taken. For pre-launch these actions include wash pump control, data system control,



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Figure 51 Programmed Event Generation

and restart. An example of a possible prelaunch stack is given in Figure 51C. Note that clock counter-time label comparisons are made on a hours-minutes basis only as this is adequate for prelaunch event accuracy and minimizes memory requirements.

The prelaunch events are self-explanatory except for restart. The restart event resets the clock counter to zero which in effect restarts the prelaunch program. This would come into use in case of extended launch delays (greater than ≈ 12.5 hours).

One last point that should be noted is that the time compare routine looks at time labels sequentially and therefore requires that they be in time ascending order. For example after a match and event has occurred the program will move to the next time label in the stack and wait for a match. If this time label is less than the first time label no match will ever occur and the program will hang up. However since the stack is programmed in ROM and is therefore fixed, this is really a nonproblem. In the experiment stack, to be described later, the events need not be stored in time order and a slightly different, less efficient comparison routine is used.

The prelaunch routine also contains one other step which is critical to experiment performance: that is the loading of the experiment profile from ROM to RAM at power on. This is necessary due to the inaccessibility of the microcomputer at power-on plus the requirement to perform several events after launch and prior to ground-link initiation at $t_0 + 12$ hours. The details of the experiment profile will be described later.

Termination of the prelaunch routine may occur at any time and is caused by the signal of an acoustic transducer indicating launch. This $t = 0$ signal will cause the following actions to occur:

1. An output to reset the data system. This will halt any actions in progress.
2. An output to start the applicable parts of the data system for ascent data recording.
3. Reset the clock counter to zero.
4. Set the experiment time label/event word stack as the active control.

With these steps completed the main program is initiated.

Main Program

A simplified flow chart of the main program and the interrupt program is shown in Figure 52 and 53. The operation of the event versus time output is very similar to that described for prelaunch although there are some important differences which will be pointed out.

As during prelaunch a clock counter, updated every second, defines the experiment time line and is stored in four registers in RAM as shown in Figure 54A. There is also a time label/event work stack which is now stored in RAM. As noted earlier this stack, which contains the experiment events versus time is originally stored in ROM and, as a part of the initialization procedure, is transferred to RAM. This stack must be in RAM as it is subject to change during the mission as described later. A diagram of the time label/event word stack is shown in Figure 54B. Note that in this case the time label consists of days, hours, and minutes.

The compare operation is performed by comparing the clock counter with the first time label in the time label/event word stack. If the two times are not equal the second time label would be compared to the clock counter and so on. This would continue until either the end of stack was reached at which the program would say no match and continue on to other functions, or a time label match was found. When a match is found the corresponding event word is decoded (see below) and the defined

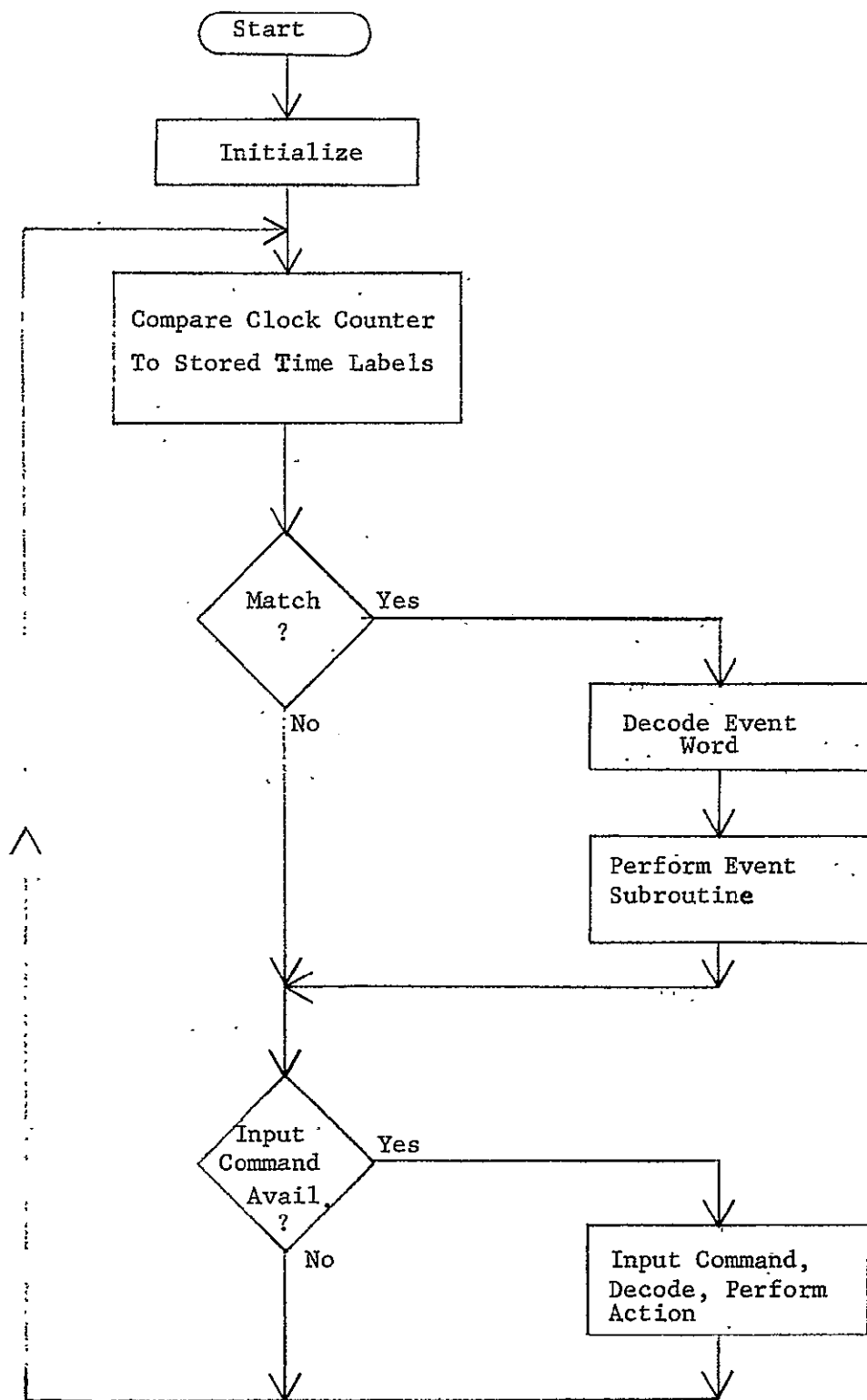


Figure 52 Main Program Flowchart

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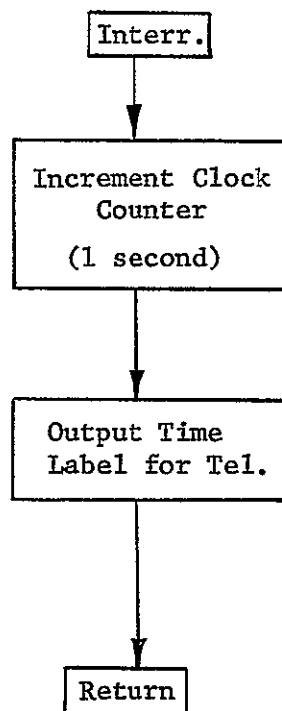


Figure 53 Interrupt Program

Days	} Clock Counter
Hours	
Minutes	
(Seconds)	

A. Clock Registers

Day
Hour
Minute
Event Word
Day
Hour
Minute
Event Word
Day
Hour
Minute
•
•
•
•
Day
Hour
Minute
Event Word

B. Time Label/Event Word Stack

Figure 54 Main Program Stack

action taken. Also the executed event word and its' time label will be deleted from the stack and the rest of the stack will be moved up to fill the now vacant registers. See Figure 55. Any new time labels/event words will be appended to the end of the stack.

In summary then, during the compare routine, all time labels in the stack are compared to the clock counter. Because of the microcomputer speed, the comparisons will take place many times. Any match results in execution of the event word and deletion of that word and its' time label from the stack. Added time label/event words are put on the bottom of the stack.

The number of events that can be placed in the stack at any one time is determined by the RAM space available. The preliminary design has 2K bytes of RAM. Approximately 100 bytes are needed for program use which leaves 1948 bytes. Each event requires 3 bytes of time label and the one byte event code. So dividing the available 1948 bytes by 4 bytes/event gives 487 events. This is adequate for an eight day mission.

As stated before at a time match, the event word will be executed. It is now necessary to look at the event words and to explain what functions occur because of them. The four event words are described in Figure 56. The event codes each call up a separate subroutine; a spin-cycle, a steady g, equiv. spin or data control. Each subroutine is described in detail in the next section.

Interrupt Program

The interrupt subroutine both updates the clock counter every second and outputs the entire clock counter contents on a 24-bit parallel line. This routine is to be written in a very efficient manner so that its occurrence has minimal effect on the operating program. It is flow charted in Figure 53.

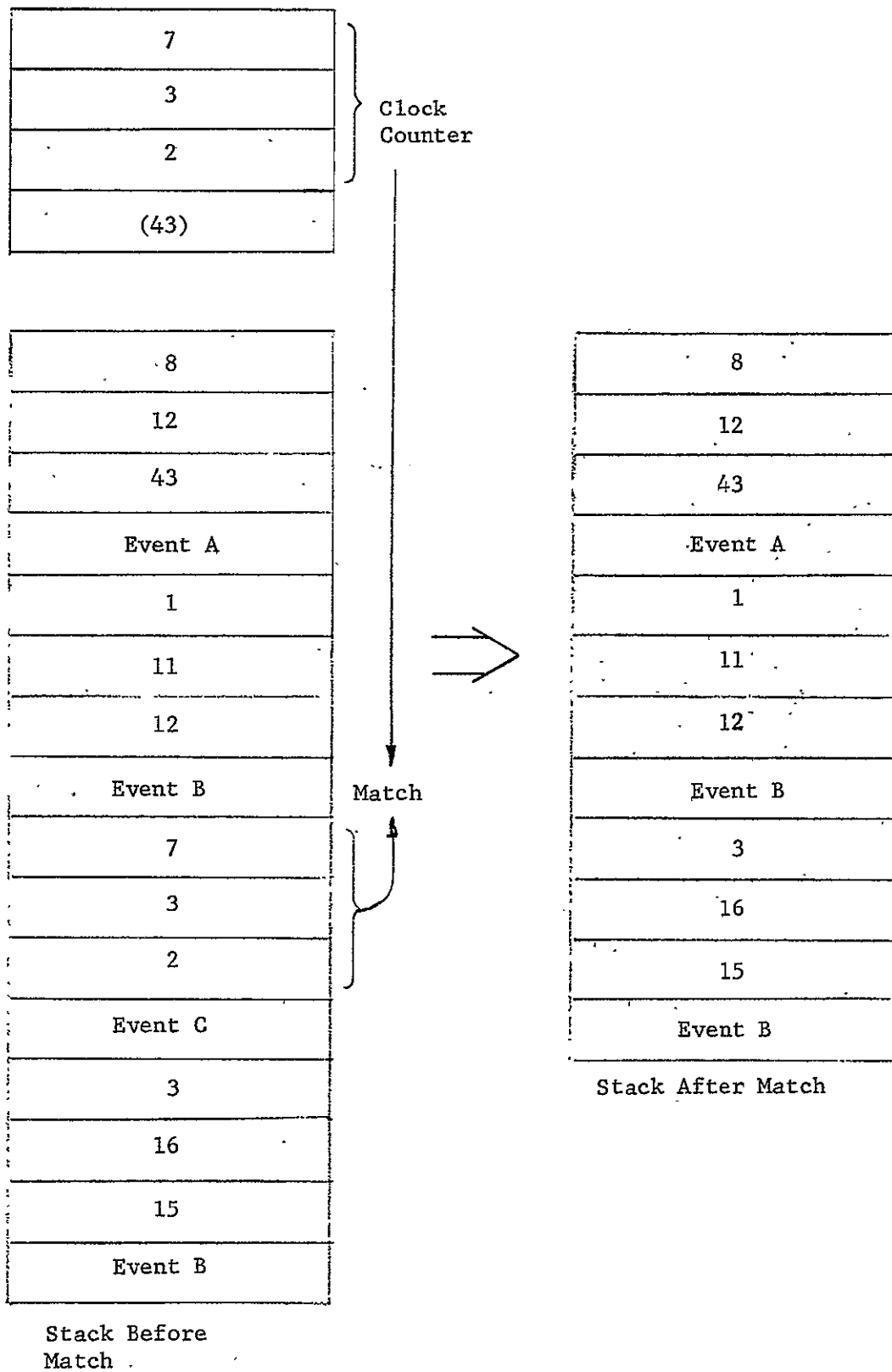


Figure 55 Stack Operation

Data System Control

0	0	0/1	0/1	0/1	0/1	0/1	0/1
---	---	-----	-----	-----	-----	-----	-----

Control Code

Spin Cycle

0	1	X	X	X	X	X	X
---	---	---	---	---	---	---	---

Steady G.

1	0	X	0/1	0/1	0/1	0/1	0/1
---	---	---	-----	-----	-----	-----	-----

Rate Level (1 of 20)

Equiv. Spin

X: Don't Care

1	1	X	0/1	0/1	0/1	0/1	0/1
---	---	---	-----	-----	-----	-----	-----

Rate Level (Same as Steady G)

Figure 56 Event Words

Spin Cycle

The spin cycle is a well defined function of g versus time or an equivalent ω (centrifuge rate) versus time $g \sim \omega^2$. The function is called up when an event word, 01XX XXXX is found at a time match.

The subroutine performs the following steps:

1. Position canisters to 0° .
2. Delay until positioning has been completed.
3. Output stored ω vs stored time (spin up)
4. Hold at constant ω (steady g)
5. Output stored ω vs stored time (spin down)

Steps 1 and 2 are implemented by simply outputting a 0° degree position word and then doing a software loop for a period of time.

Steps 3, 4 and 5 are performed in a way similar to that of the prelaunch event control but for clarity will be described again.

For this subroutine considerable accuracy is required. Therefore the clock resolution is set at .002 sec. This 500 Hz signal derived from the crystal oscillator, is input to a 16-bit binary counter which serves as the subroutine time base.

The ω versus t profile is stored in ROM in the format shown in Figure 57. Two comments about the table are in order. The first is that only the 8 least significant bits are stored for each time label. This is feasible since, because the table is fixed (it is in ROM) it can have ascending time labels. Thus while the same time label may appear twice in the stack only one (the first) is acted on at once. The second item to notice is that the ω (centrifuge rate) word requires two registers. This is because to achieve the accuracy necessary for the spin cycle the ω words had to be 11 bits wide to give 2048 ω levels with 8 bit registers it is necessary then to use two to hold all 11 bits.

Time Label LSD #1
W_1 (LSD)
W_1 (MSD)
Time Label LSD #2
W_2 (LSD)
W_2 (MSD)
Time Label LSD #3
W_3 (LSD)
W_3 (MSD)
⋮
Time Label LSD #N
$\emptyset$
$\emptyset$

(Last Rate Output Always zero)

Figure 57 Spin Cycle, Rate vs Time Table

As described in earlier sections the ω (rate) words will be output by comparing the time label LSB's with the binary counter LSB's. When the two are equal the 11 bit ω (rate) word will be sent to the centrifuge controller. Then the next time label LSB's will be compared to the binary counter LSB's until a latch is made and so on. The subroutine will stop when $\omega = 0$ is output to the centrifuge.

One detail which has to do with this and other subroutines needs some discussion. The main experiment clock [days, hours, minutes] is updated as needed by a 1 sec or 1 Hz input. This input can occur at any time the main program is running and since it is an interrupt it seemingly could negatively affect the spin cycle and equivalent spin subroutines. However the event time resolution for the subroutines is .002 secs or 2000 microseconds. This small jitter, which occurs at 1 second intervals will not effect the g versus time accuracy required.

A flow chart of the spin cycle subroutine is given on Figure 58.

Data System Control

The data system control subroutine is very simple. It is called up by an event word of the form $\phi\phi\phi/1 \ \phi/1 \ \phi/1 \ \phi/1 \ \phi/1 \ \phi/1$ where the first two bits ($\phi\phi$) identify it as a data system control event and the last six bits form a binary word. The subroutine consists entirely of outputting this binary number to the data system where it is decoded and the appropriate actions taken.

Steady g

The "steady g" subroutine allows the canisters to rotate at a constant angular velocity thus simulating a fixed "gravity" environment. This subroutine allows the selection of any one of 20 g levels from 0 g to 1.0 g in .05 g steps. The particular level is contained in the event word which is of the form $1\phi X \ \phi/1 \ \phi/1 \ \phi/1 \ \phi/1 \ \phi/1$. As usual the first two bits define the subroutine: 1ϕ = steady g; the third bit is

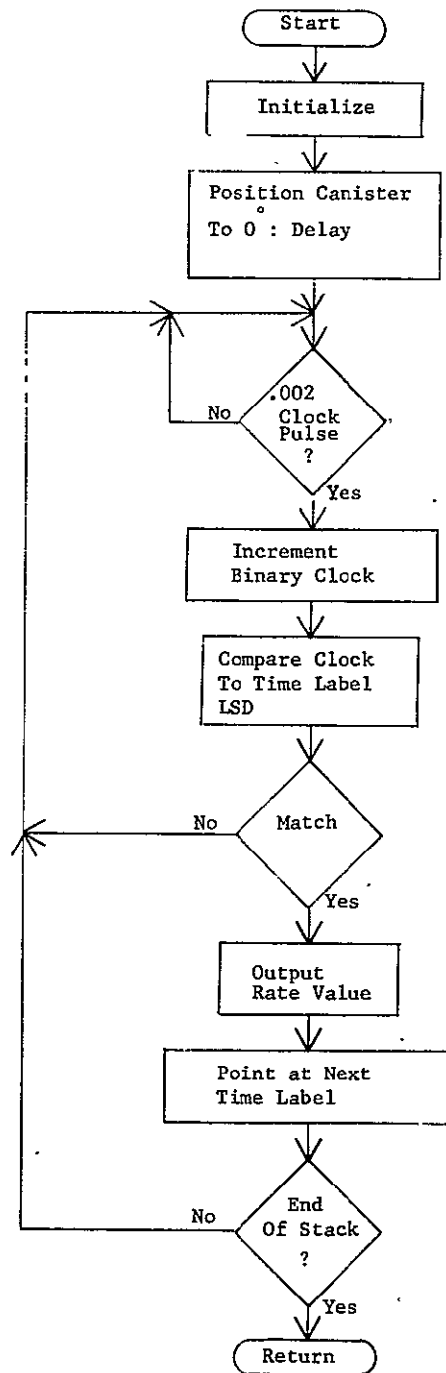


Figure 58 Spin Cycle Flow Chart

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a don't care and the last 5 bits select one of twenty g levels. The subroutine, then, follows the steps:

1. Position canisters to 90° .
2. Delay (to complete positioning).
3. Decode six bits of event word into 11 bit rate code.
4. Output (and hold) rate code.

One point to note is that to complete a steady g cycle two events are required: the first event is to set the g level to its' desired value; the second event is to set the g level to zero (stop the centrifuge). This method facilitates long steady g periods by eliminating an explicit timer. It also allows other subroutines, in particular the equivalent spin subroutine to be superimposed on a steady-g level.

Equivalent Spin

The equivalent spin subroutine is very similar to the spin cycle in substance with many differences in detail. For example, the equivalent spin subroutine is called after a steady g subroutine has been executed with $g \neq 0$. The equivalent spin subroutine in essence does the following:

1. Output canister position vs. time
2. Output centrifuge rate vs. time

where time is incremented and compared exactly as is done for the spin cycle. Note that the particular position vs time and rate versus time profiles are dependent upon the existing steady g level. The event code for a steady g subroutine is: 11 x $\phi/1$ $\phi/1$ $\phi/1$ $\phi/1$ $\phi/1$. The first two bits, 11, identify this code as an equivalent spin subroutine: the last five bits indicate the existing steady g level. Note that these bits will always be the same as those found in the previous steady g event word.

When the equivalent spin subroutine is initiated (by the time label matching the clock counter) the steady g level code is used to select the correct position vs time and rate vs time profiles. These profiles are output in the same manner as the spin cycle subroutine with the addition of a comparison to the position table as well as the rate table.

System Interfaces - Commands and Telemetry

The other major part of the main program is that which handles the command and telemetry functions. The command inputs include:

1. Add a time label/event word to the time label/event word stack.
2. Delete a time label/event word from the time label/event word stack.
3. Set the clock counter to any value. (Seconds automatically set to zero).
4. Request output of specified microcomputer memory locations.

Command and telemetry interface with the basic microcomputer through standard 8-bit parallel I/O ports.

The format of the commands are as shown:

- Byte #1: Command Word: Identifies type of incoming command to microcomputer.
- Byte #2 - #5: Data: Such as time labels, event codes, etc.
- Byte #6: End Command Word: Signals microcomputer that all data has been input; may contain error checks.

The four commands, along with their associated formats are listed below along with the software considerations for each.

Command #1: Add Time Label/Event Word

Command Format:

Byte 1:	Command Word
Byte 2:	Day Label
Byte 3:	Hour Label
Byte 4:	Minute Label
Byte 5:	Event Word
Byte 6:	End of Command

Software: The programming for this function will be based on handling the time label/event word stack as follows. The stack is kept to a minimum size by deleting a time label/event word when it is executed and by moving the rest of the stack up 4 locations to fill the deleted bytes. All additions to the stack are made to the lowest unoccupied locations adjacent to the stack.

There are other techniques: this one minimizes required stack space and allows rapid stack review, during time comparison operations.

Command #2: Delete Time Label/Event Word

Command Format	Byte 1: Command Word
	Byte 2: Day Label
	Byte 3: Hour Label
	Byte 4: Minute Label
	Byte 5: (Filler)
	Byte 6: End of Command

Software: For this function the three time labels are read in and then sequentially compared with each time label in the time label/event word stack. When a match is found the stack time label and event word is deleted and the rest of the stack is moved up four locations.

Command #3: Clock Set

Command Format	Byte 1: Command Word
	Byte 2: Day
	Byte 3: Hour
	Byte 4: Minute
	Byte 5: (Filler)
	Byte 6: End of Command

Software: This command can set the experiment time to any predetermined value. By loading the command data bytes into the clock counter registers. During this load time the interrupt system will be disabled to avoid any conflicts. The seconds register will automatically be set to zero for any clock reset or load operation. Upon completion of the clock set, the interrupts will be enabled and the main program will continue.

Command #4: Output Contents of Memory

Command Format	Byte 1: Command Word
	Byte 2: Starting Memory Addr.-MSB
	Byte 3: Starting Memory Addr.-LSB
	Byte 4: No. of locations to be output
	Byte 5: (Filler)
	Byte 6: End of Command

Software: The memory output command utilizes the CPU DMA capability to output a specified number of bytes from memory to the telemetry data port. This information can be used to verify the time label/event word stack, the clock counter registers, etc.

To perform this action the software will use the first two data bytes to set up a memory pointer and the third data byte will be used as an output counter. With the initialization complete, the first two bytes output will be the memory starting address. Following them will be the N bytes of memory contents. All outputs go to the telemetry port and system interface circuitry where the parallel words are converted into a serial bit stream.

Memory Map

A preliminary memory map is given in Figure 59.

Hardware Design

The microcomputer is based on the 1802 microprocessor, a CMOS device which requires very little power for operation. Peripheral chips, such as memories, I/O ports, and other logic will also use CMOS technology so that the entire microcomputer will use minimal power. For this application the 1802 microprocessor characteristics fit in well. The program requires only minimal arithmetic capability, but does use tables extensively which is compatible with the architecture of the 1802. A block diagram of the microcomputer is given in Figure 60.

An integral part of the 1802 CPU and its software philosophy are the sixteen scratch pad registers contained on the CPU chip.

It should be noted at this point that the 1802 microprocessor was selected because it is the best microprocessor available at this time for this job. There is a proposal for a standard "off-the-shelf" microcomputer to be used for spacelab experiments. Should details of this unit prove it to be a

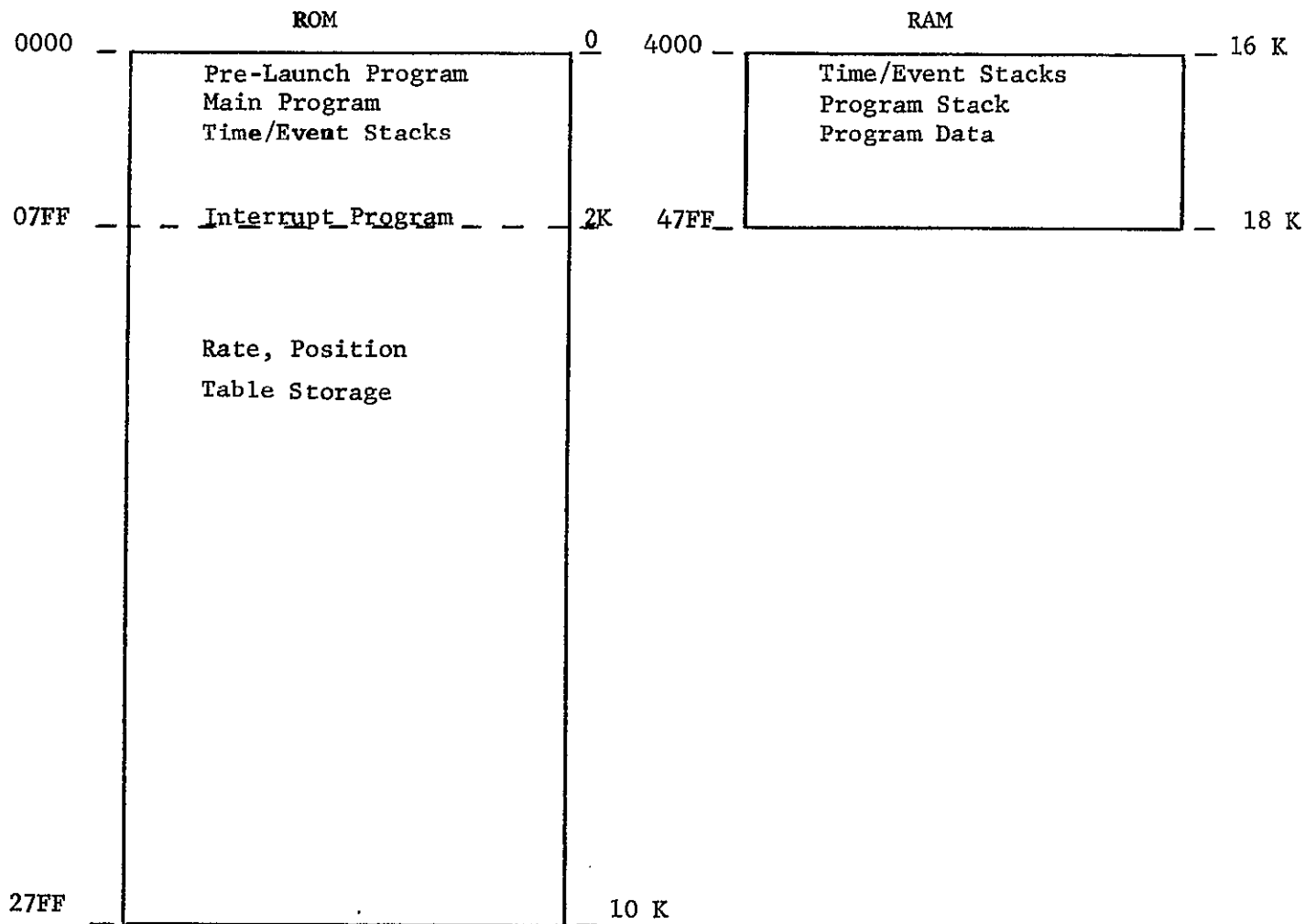


Figure 59 Memory Map

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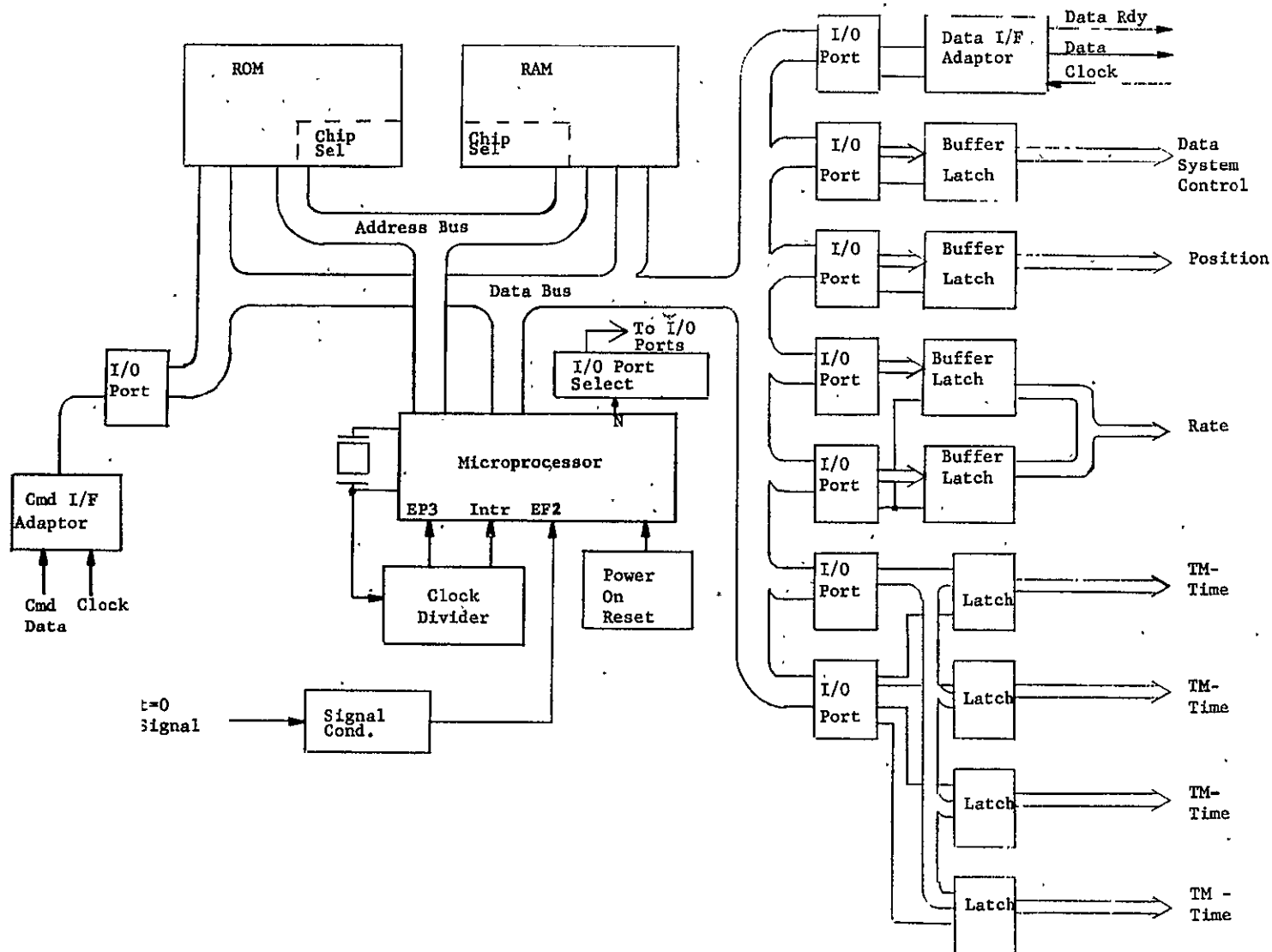


Figure 60 Microcomputer Block Diagram

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feasible replacement for the microcomputer described herein, it would certainly seem to be the best approach. However one must be careful in trying to use a "standard" microcomputer. In general it is better to select the microcomputer based on the application.

Memory

ROM: The read only memory will consist of 10 1024x8 memory chips, part number CDP 1834. These chips are pin compatible with the 2708 UV PROM which can be programmed, erased and reprogrammed as often as necessary during system integration tests. A CMOS erasable PROM is in the planning stage; should it become available it would be used in place of the 1834.

RAM: The read/write memory will be made up of 16 256x4 memory chips to give a total of 2K bytes of RAM. The chip part number is CDP 1822.

Note

As new memory chips are constantly being introduced, the chips selected for the final design may not be identical to those listed above. A complete review must be made at that time to determine the optimum memory design.

I/O Ports

Eight I/O ports are required for the system: one input port for commands, one output port for telemetry, one output port for data system control, one output port for canister position data, two output ports for rate data and two output ports for time label output. For maximum capability and ease of design the CDP 1852 I/O port will be used to implement the I/O function. Additional peculiar interface circuits may be required to insure system compatibility.

Miscellaneous Functions

Chip Select: Addressing the RAM and ROM memories requires decoding the higher order address bits. This will be accomplished using CMOS decoders, part number 4556 and some miscellaneous NAND and NOR gates.

Address Latch: A CDP 1852 I/O port will be used in a latch mode to demultiplex the 1802 address lines.

Clock: The 1802 microprocessor requires only a crystal, one resistor and two capacitors to generate a clock signal. For this application a 2.048 MHz crystal will be used.

Interface

The three experiment interfaces (data system port, position port and rate port) will interface to the rest of the system through low-power Schottky latches (74LS273).

The time label output will similarly be on LSTTL latches.

A more complicated interface is that with the command-telemetry system. The high rate, bit serial format of the command input must be converted into a byte serial format with the byte input rate determined by the microcomputer software. For the telemetry output, the reverse process is required.

The CMD sync circuit will insure that the command data and command clock are adjusted to be compatible with the FIFO buffer memory. This requires deletion of the last command bit (the parity bit) and deletion of the last clock pulse. With these modifications, twobytes will be loaded into the FIFO for each command word. The FIFO will load bit serially, format the data into 8-bit bytes and shift the bytes to the FIFO output where they can be read, byte by byte by the microcomputer under software control.

The data output adaptor takes the parallel data from the I/O port and puts it into the FIFO from which the data can be read serially under command system control. The output format circuit must keep track of the number of words loaded into the FIFO since they are clocked out in pairs and it must also add a parity bit to the data word.

Mechanical Design

Table 10 gives a preliminary parts list for the microcomputer not including power supply parts. Using this list as a guide an estimated size and weight for the unit was derived and is presented in Figure 61.

Life Support System

The life support system is designed to meet the system requirements for an eight day mission with a 50 percent reserve of expendables. Figure 62 presents a schematic of the system which includes a thermoelectric cooling unit with a controller and cabin air blower to cool the liquid, a high pressure oxygen storage bottle to store metabolic oxygen, a regulator to reduce the high pressure to the required operating pressure, a lung to supply oxygen to the water and remove carbon dioxide from it, a baralyne canister to remove the carbon dioxide from the oxygen stream, a filter to catch solid wastes such as the frog's excess skin, and liquid accumulator to accommodate thermal expansion and keep the liquid side of the lung slightly higher than the gas side, and a circulation pump to circulate the water from the life support system to the frog canisters. Also included are an air pump to circulate gas from the lung through the baralyne canister for carbon dioxide removal, a wash pump to provide the high flow rate necessary to wash the frogs, a water tank to allow sufficient liquid volume for urea control, and various minor components such as quick disconnects, valves, pressure and pH sensors, lines and fittings.

The thermoelectric method of cooling was chosen as it offers a reliable means of providing cooling with no moving parts or potentially hazardous gases..

The unit rejects heat directly to the cabin air and requires only an electrical connection to operate.

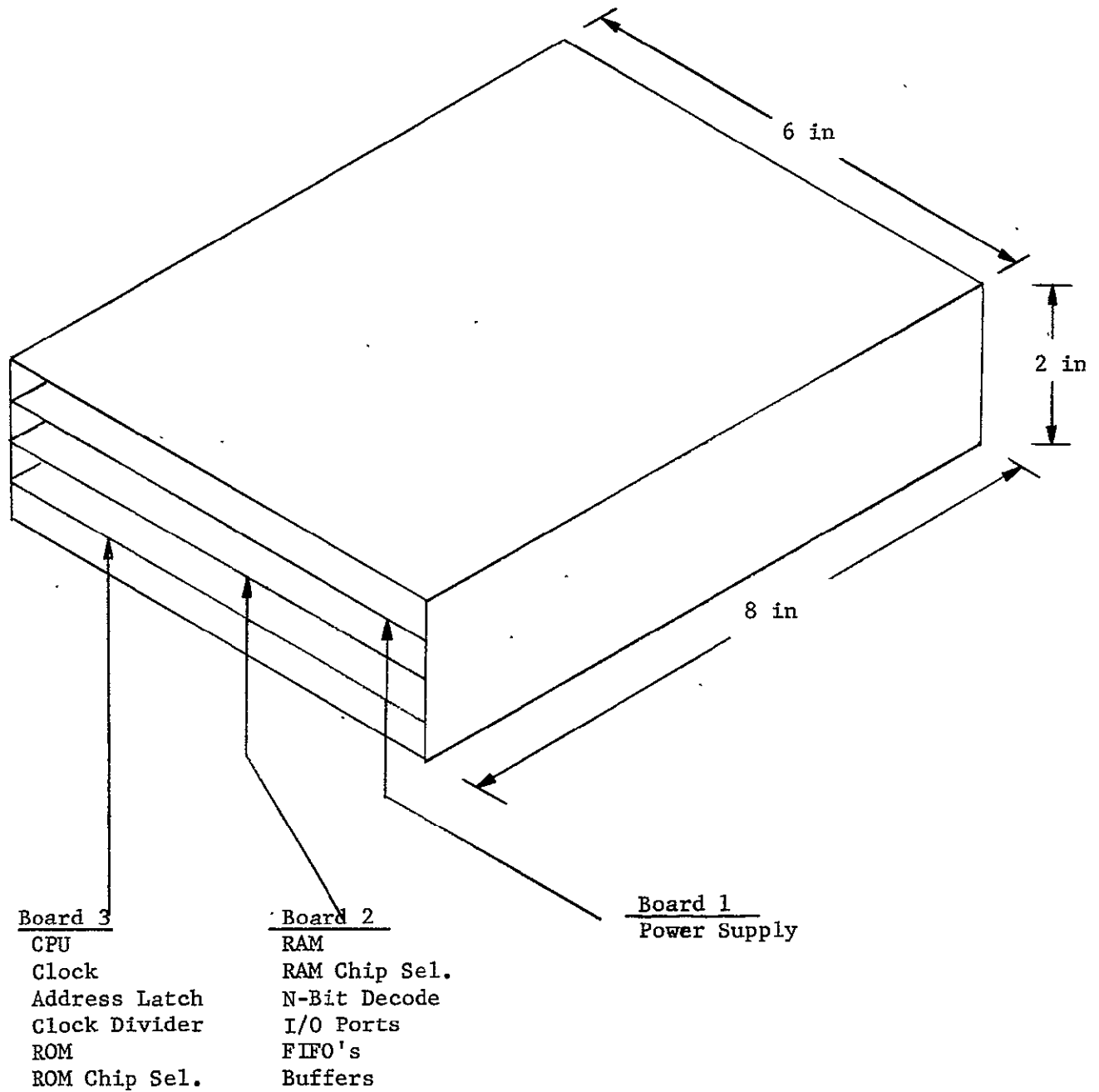
A vehicle cold plate is available in the Spacelab but is not used, because (1) it is several racks away from the life support system, (2) it is difficult to electrically isolate, and (3) there is only a small weight

Table 10
Microcomputer Parts List*

<u>Function</u>	<u>Part Number</u>	<u>Quantity</u>
CPU	CDP 1802	1
Address Latch	CDP 1852	1
Chip Select	CD 4556 B	3
	CD 4001 B	3
	CD 4011	1
ROM	CDP 1834 (2708)	10
RAM	CDP 1822S	16
Clock	2.048 MHz Xtal	1
Clock Divider	CD 4040B	1
	CD 4518B	2
	CD 4069B	1
N-Bit Decoder	CDP 1853	1
I/O Port	CDP 1852	8
FIFO	AM 2812	2
Buffers, Etc.	74LS 273	7
	CD 4069B	1

*Does not include Power Supply, Mechanical Parts or Discrete Components.

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Weight 5 lbs.

Figure 61 Microcomputer - Mechanical

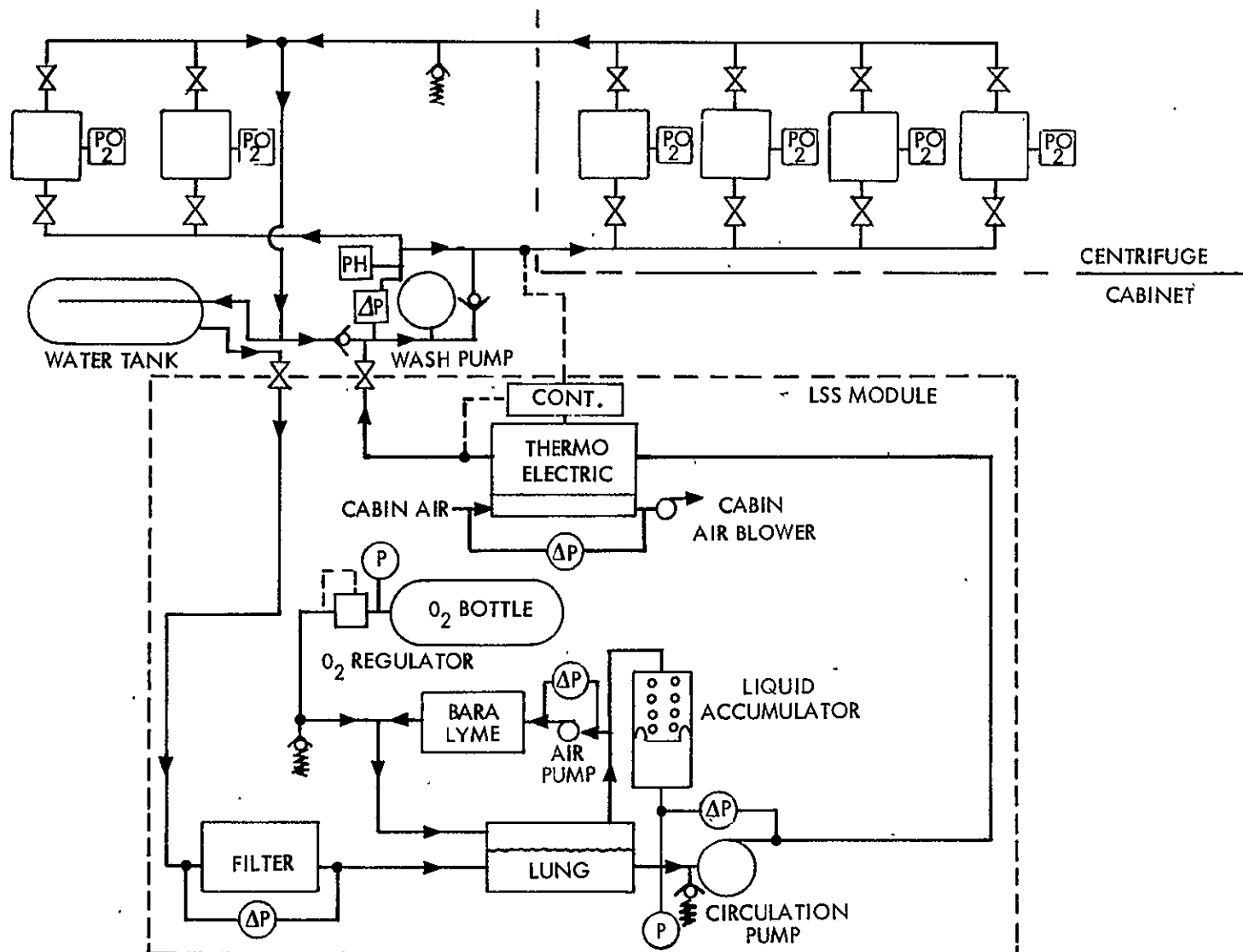


Figure 62 Life Support System Schematic

savings associated with its use. If an average cooling power of 30 watts is assumed, a 0.8 lb gas/Kw hr fuel cell penalty combined with an assumed supercritical tank weight of 0.35 lb tank/lb gas results in a weight penalty of only 6.2 pounds for an 8 day mission. This is probably less than the weight of the equipment needed to interface with the cold plate.

Oxygen stored in a high pressure reservoir provides the gaseous oxygen required in the circulating gas loop. Oxygen is fed into the gas loop by an absolute pressure regulator which maintains a constant pressure independent of cabin pressure fluxuation. Baralyme was chosen for the carbon dioxide removal chemical as it is stable in a high humidity environment. Although other chemicals are potentially slightly more efficient from a weight standpoint, lack of experience with them and the short mission duration precluded their use.

Filtration of frog wastes from the water is complicated by the shedding of the frog's skin. Large skin particles can easily clog a conventional filter. Therefore, a two stage filter design was developed. It uses a coarse outside screen to remove frog skin, and a fine pleated screen cartridge to remove smaller particles.

The liquid accumulator is a conventional bellofram unit. It is internally spring loaded to keep the liquid side of the lung slightly higher in pressure than the gas inside. This prevents gas from entering the liquid loop. Liquid will not leak through the membrane pores. The accumulator also accommodates liquid expansion in the system, and provides makeup liquid for small leaks.

Urea control is by allowing buildup in the water. A flow through water tank is provided to allow sufficient liquid volume to keep the system urea concentration below 50 ppm for 12 days.

Specimen feeding is accomplished by the payload specialist using a syringe of liquid food that interfaces with a valve on the canister lid.

System Operation

During system operation, water is circulated through the frog canisters by a liquid pump at a rate of 500 cc per minute, resulting in a flow of 0.8 gpm through the life support module.

Water flows from the frog canisters through the filters to remove solid particles, through the lung where oxygen is supplied and carbon dioxide is removed, and to the circulating pump. The liquid accumulator is located at this point and keeps the water pressure from 0.5 to 1.5 psi above the lung gas side pressure, depending on the accumulator piston position. Since the nominal gas pressure is 20 psia, the nominal liquid pressure is 20.5 psia. As shown in Table 11, the circulating pump boosts the pressure by approximately 13.2 psi. The wash loop pressure drop summary is also presented. Downstream of the circulating pump the flow passes through the thermoelectric unit and then returns to the canisters.

The thermoelectric module elements are divided into 4 sections. The controller senses coolant temperature to the capsules and controls the module power by proportioning one section, and turning the other sections on and off as required. This allows temperature control within the $62 \pm 2^{\circ}\text{F}$ allowed in the capsule. The thermoelectric fan provides 40 cfm to cool the module. It pulls cabin air in through the front of the life support module, uses it to cool the thermoelectric unit and pump motors and then exhaust it into the cabinet.

When frog washing is required, the wash pump is energized. It provides a water flow of 0.5 gpm per frog through nozzles located over and under the frog. Temperature control is achieved by thermal lag plus the thermoelectric unit during the 20 minute wash period.

Table 11
System Liquid Pressure Drop Summary

Circulation Loop	
Thermoelectric Unit	.5 psi
Lung	2.8
Check Valve	.5
Filters (max)	3.0
Lines and fittings in module	4.0
Quick disconnects	1.4
Lines and fittings outside module	<u>1.0</u>
	13.2 psi
Wash Loop	
Lines and fittings on centrifuge	8.2 psi
Hub rotary joints	.4
Lines from rack to centrifuge	4.6
Check valve	.5
Lines and fittings inside rack	<u>1.4</u>
	15.1 psi

Table 12 summarizes the system heat loads for 75 and 90°F cabin temperature, and Table 13 summarizes life support component nominal power usage. The frog's metabolic heat, the heat of CO₂ absorption in the baralyne canister, the air pump heat, the recirculation pump heat, and cabin heat leak are all directly or indirectly added to the fluid. Also, when washing occurs, the wash pump heat is added to the fluid. It should be noted that the heat load is not equal to the total electrical power consumption of the pump, because most of the motor heat is rejected directly to the cabin air. Washing is not done when the cabin temperature is 90°F, during ascent or descent.

Oxygen is stored at 2500 psia in a spherical tank. It is reduced to 20±5 psia by an absolute pressure regulator. The oxygen is metered directly into the lung gas circuit, where oxygen is transferred into the liquid and carbon dioxide is removed from the liquid. Of the 20 psia total pressure at the lung entrance (1034 mmHg), 1016 mmHg is oxygen, 13.3 mmHg is water vapor and a maximum of 4 mmHg is carbon dioxide.

Mass transfer across the lung membrane at oxygen and carbon dioxide rates of 300 std cc/hr requires 13.3 mmHg oxygen log mean pressure difference and 4 mmHg carbon dioxide log mean pressure difference. This results in a liquid oxygen equilibrium pressure of 1003 mmHg and a maximum liquid carbon dioxide equilibrium pressure of 8 mmHg. It should be noted that this is the maximum carbon dioxide pressure which will occur. In the beginning of the mission the equilibrium pressure will be closer to 4 mmHg.

CO₂ removal from the gas stream is provided by a granular bed of Baralyne. Maximum bed outlet carbon dioxide partial pressure is 4 mmHg. Gas from the lung is constantly circulated through the bed by the air pump at a rate of 2.5 - 3 liters per minute.

pH of the water returning to the canisters is measured by a pH sensor, and oxygen partial pressure is measured at each canister. Also, pressure and differential pressure transducers are provided to monitor system status and to diagnose system problems. All signals are fed to the data system.

Table 12
Heat Load Summary

Nominal Case - 75° Cabin .

Wash Pump Off

6 Frogs	2 Btu/hr
Heat of CO ₂ absorption	16
Air pump	7
Recirculate pump to fluid	55
Heat leak from cabin	<u>113</u>
	193 Btu/hr = 57 watts

Wash Pump On

Wash pump to fluid	<u>171</u>
	364 Btu/hr = 107 watts

Max Case - 90° Cabin

Wash Pump Off

6 Frogs	2
Heat of CO ₂ absorption	16
Air pump	7
Recirculate pump to fluid	55
Heat leak from cabin	<u>243</u>
	323 Btu/hr = 95 watts

Table 13
Life Support System Power Summary

	<u>Power-Watts</u>
o Thermoelectric Unit	
90°F Cabin-Wash Pump Off	95
75°F Cabin-Wash Pump On	50
75°F Cabin-Wash Pump Off	10
o Thermoelectric Unit Fan	10
o Circulating Pump	25
o Wash Pump	73
o Thermoelectric Controller	15
o Air Pump	2

Any canister on the life support system module can be removed by unplugging the fluid quick disconnects and electrical connectors. If a canister is removed and the others are to remain active, the liquid disconnects for that unit are simply connected together so that flow balance is not disturbed.

Thermoelectric Unit

The thermoelectric unit is designed to cool the circulating frog solution and in conjunction with the controller, to maintain the solution at $62 \pm 2^{\circ}\text{F}$. The unit utilizes a number of thermoelectric modules to electrically provide a temperature difference, rejecting liquid heat to the cabin air. The unit is sized to provide 95 watts of cooling in a 90°F cabin environment. Under these conditions it draws 95 watts of electrical power for the thermoelectrics and 10 watts of fan power. The unit is designed to work on 22-37 VDC unregulated power. Due to the nature of the thermoelectric modules, electrical isolation of the liquid is automatically provided.

The unit, shown by Figure 63, consists of an air side heat exchanger, a liquid side heat exchanger, a cooling fan and duct, and a number of thermoelectric modules with wiring and an electrical connector. The overall size is 10 inches x 8 inches x 2.8 inches, and the unit weighs 13.1 pounds.

The air side heat exchanger has 32 rows of fins $1\frac{1}{2}$ inches high and 4" long. There are 12 fins per inch, and the fins are 0.006" thick. The 0.1 inch thick spacers are 0.208" apart, and the bottom plate is 0.125 inches thick. It is constructed of copper for good heat transfer, and the assembly is brazed together.

The liquid side heat exchanger is constructed of stainless steel and has a single fluid pass about 4 inches wide and 9.5 inches long. It has approximately 26 fins per inch of 0.006 material, .102" high and the upper and lower plates are brazed to the core. After brazing the

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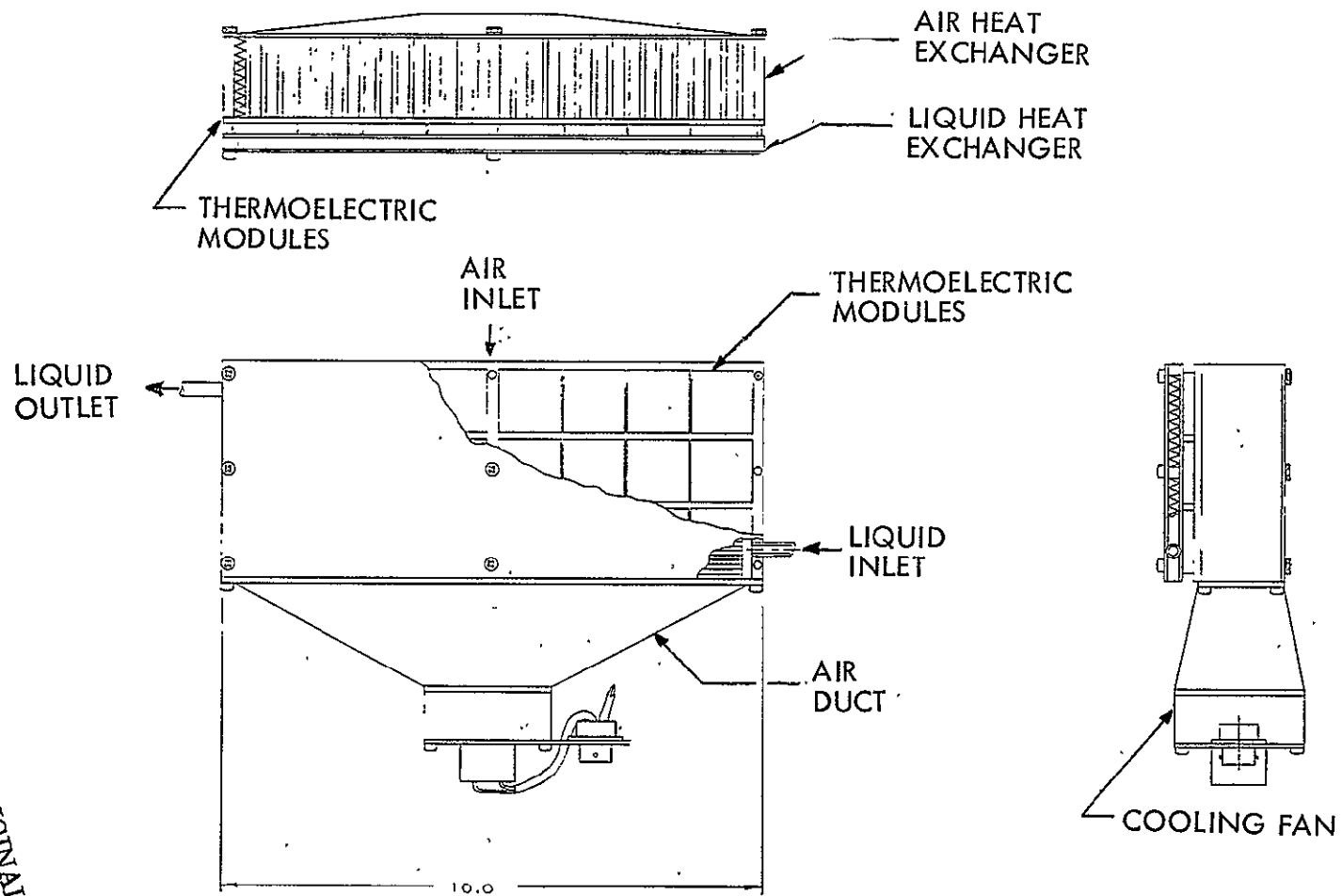


Figure 63 Thermoelectric Unit

thermoelectric mating surface is ground flat. The fluid inlet and outlet are located at opposite corners to provide uniform fluid flow.

The cooling fan is a Buehler model 59.112. It is DC operated and provides in excess of 40 cfm at 0.06 inches of water head rise. It is attached to an aluminum air duct assembly which, in turn attaches to the air heat exchanger. Air flow is over the core and out of the fan. Twenty-four thermoelectric modules are used. They are 1.15 inches square and about 0.2 inches thick. They are similar to Borg Warner model 930 and are wired 6 in series, in 4 sections, to operate directly from the 22 - 32 VDC supply.

The thermoelectric modules are soldered directly to the air heat exchanger. The interface between the modules and the liquid heat exchanger is covered with thermal grease and nine bolts applying a uniform clamping pressure to assure good thermal performance. Non metallic spacers under the bolts on the liquid side provide electrical isolation.

At maximum load the unit operates between the 62°F water and a 90°F cabin, and removes 95 watts of heat from the water. At this load the coefficient of performance is 1 and therefore the unit must reject 190 watts to the cabin air. Under these conditions, the water to thermoelectric module ΔT (including the thermal compound) is between 6 and 7°F, and the water ΔT at 0.86 gpm is about 0.9°F. With the 40 cfm fan, the 90°F cabin air will exit at 95°F. This requires the hot junction of the thermoelectric module to operate at 110°F.

At 40 cfm, the air core ΔP is 0.06 inches of water, and at 0.8 gpm the liquid side ΔP is less than 0.5 psi.

At lower cooling requirements the coefficient of performance improves greatly. For instance, with a 70°F cabin and the wash pump running the COP = 2.6 and the power consumption is only 40 watts. In the nominal 75°F cabin case with the wash pump off, the power consumption is about 10 watts.

Thermoelectric Unit Controller

The controller regulates the operation of the thermoelectric module in order to hold the desired $62 \pm 2^{\circ}\text{F}$ frog water temperature. It is designed to work from the unregulated 22-32 VDC spacecraft power supply, and has a overall efficiency greater than 97% under all conditions, not counting the small amount of power it takes to drive the logic and sensing circuits.

The controller regulates 4 sections of thermoelectric modules. One section is controlled in a fully proportional manner, the others are turned on or off as required. As time proportioning is used, and other modules are either on or off, there are no direct power losses other than those inherent in the switching elements themselves.

As shown by Figure 64, the unit uses thermistor sensing to achieve high accuracy. IC6, the ramp generator, and IC5D function as the proportional controller. The ramp generator signal has a time period (t1) and is fed to the non inverting input of IC6. The voltage signal from the center of the combination of resistances R1 and the thermistor is fed to the inverting input of IC6. If the thermistor has a negative temperature coefficient, higher than desired temperatures will produce a lower than normal voltage. As long as this voltage is higher than the voltage from the ramp generator, the comparator is off, and through IC5D and the drive transistor, the thermoelectric module is off. As the ramp generator voltage rises, the module is turned on. The circuit then keeps the module on for some percentage of the time period (t1), and turns it off as the ramp ends. Due to the nature of the time proportioning circuit, the temperature approaches the set point in an exponential fashion, thus allowing very precise temperature control. The capacitor and resistor at the capacitor input terminals produce a slight amount of hysteresis to prevent oscillation.

IC 1,2,3,4, and 5A,B and C function as a switching network to turn on and off thermoelectric sections as required. If IC6 cannot control the temperature within its bandwidth, then either IC1A or IC1B will produce a positive signal, depending on whether the temperature is too hot or too cold.

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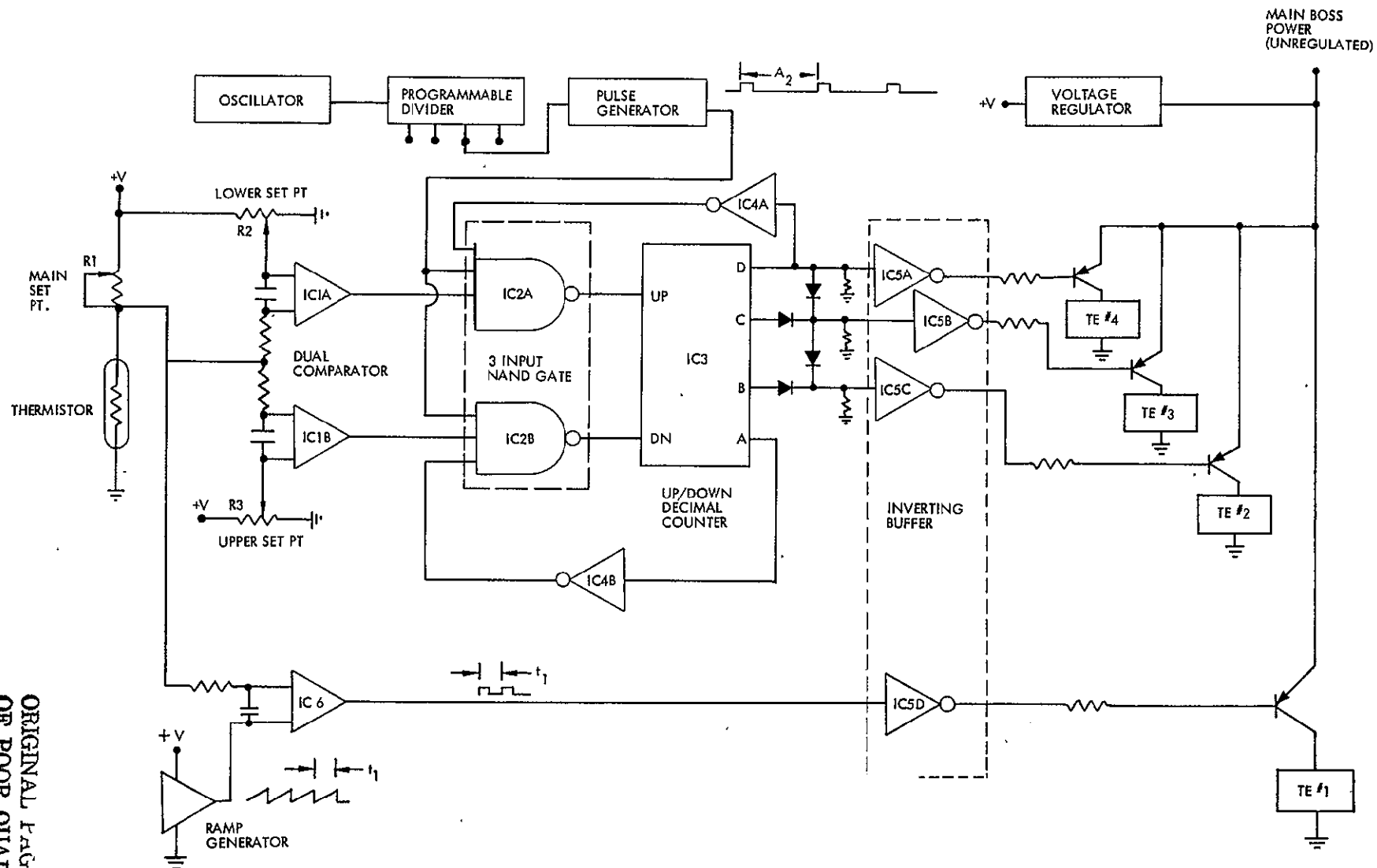


Figure 64 Thermoelectric Unit Controller

An oscillator divider, and pulse generator are used to produce a gating signal which prevents the load from changing more than one step at a time. The programmable divider allows adjustment to suit the system time constant.

If the system temperature is too high, IC1A will produce a signal indicating that more thermoelectric modules should be switched on. Upon receipt of a clock signal, IC2A will gate IC3, and cause it to count up, thus turning on one additional thermoelectric module. If the temperature is too low, IC1B and IC2B cause the counter to count down, thus turning off one additional module. IC4A or B functions to disable IC2A or B if all modules are either on or off.

Although the thermoelectric modules operate from the unregulated power, the logic can not. Therefore, a voltage regulator is required. IC5 merely acts as a buffer between the logic and the transistors which drive the thermoelectric modules.

Bipolar comparators will be used. Either CMOS or low power TTL logic can be used, depending upon specific detailed requirements.

The overall controller will be packaged in an aluminum case having overall dimensions of 2x4x6 inches, and will weigh approximately one pound.

Lung

The lung is used to supply oxygen to the circulating frog solution and to remove carbon dioxide from it. This is done by direct diffusion to the water.

A commercial unit made for clinical use with blood was chosen, as it met all requirements, is readily available, and has been extensively used. The Kolobow lung is manufactured by Sci-Med Inc., and consists of a sealed,

reinforced silicone rubber membrane envelope with a plastic spacer inside. Figure 65 illustrates the lung design. The envelope is spirally wound, and is encased in a polycarbonate case. Gas flow is through the spiral of silicone, and liquid flow is across the coil. The unit chosen has about .8 square meters of membrane area. It is about 3 inches in diameter and 12 inches long, and weighs 1.8 lbs.

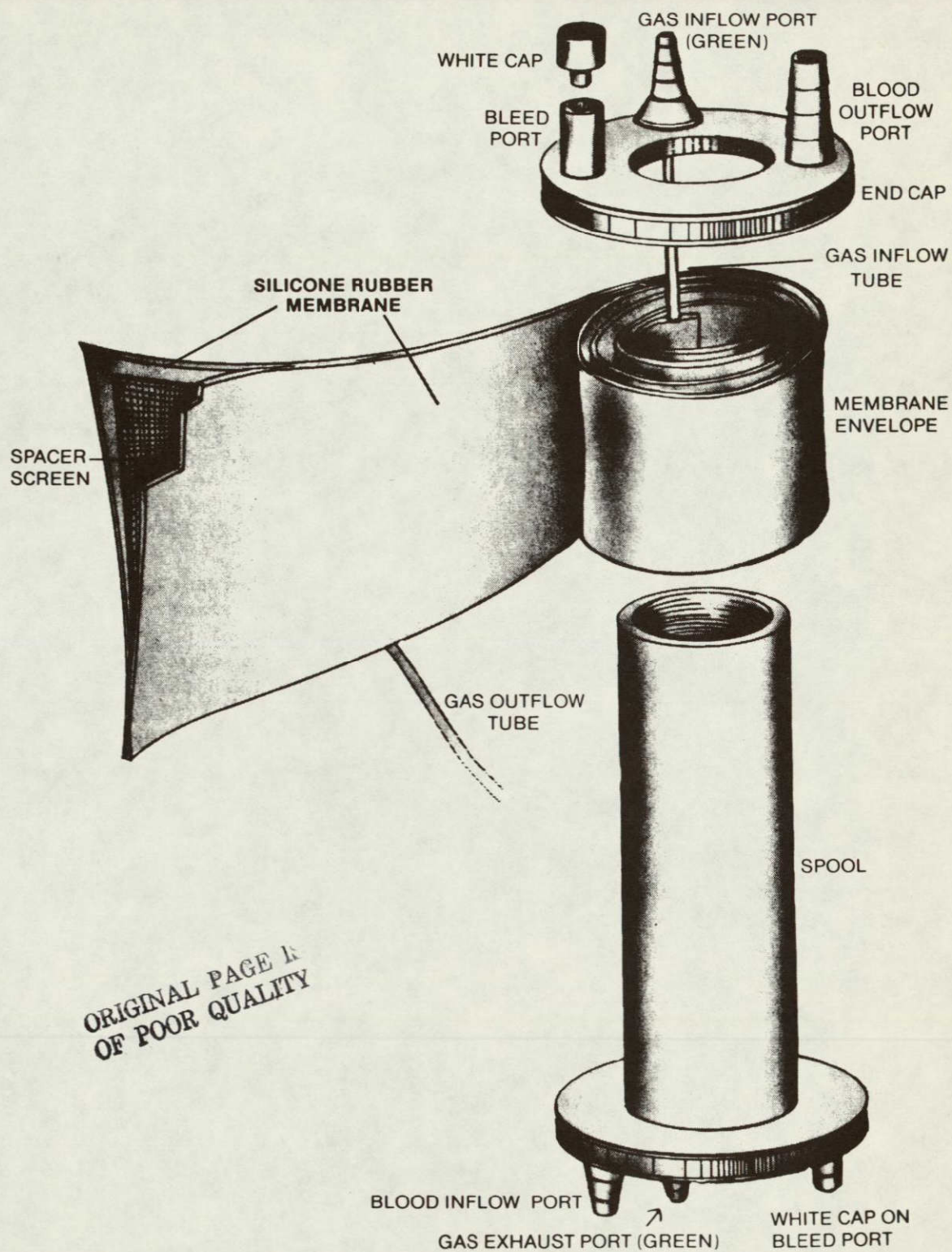
Six frogs consume 300 std cc of O_2 per hour, and produce a similar amount of CO_2 . Gas mass transfer diffusion coefficients through the lung membrane of 80×10^{-9} std cc cm/cm² sec mmHg for oxygen and 270×10^{-9} for CO_2 produce a log mean pressure difference of 13.3 mmHg for oxygen and 3.9 mmHg for carbon dioxide. Thus the gas side oxygen partial pressure must be maintained 13.3 mmHg above the desired oxygen partial pressure in the water, and the gas side CO_2 partial pressure must be maintained 3.9 mmHg below the desired CO_2 partial pressure in the water.

Liquid pressure drop at 0.8 gpm is about 2.8 psid, while the gas side pressure drop is very small at the expected 2.5-3 liter/min flow rate.

Baralyme Bed

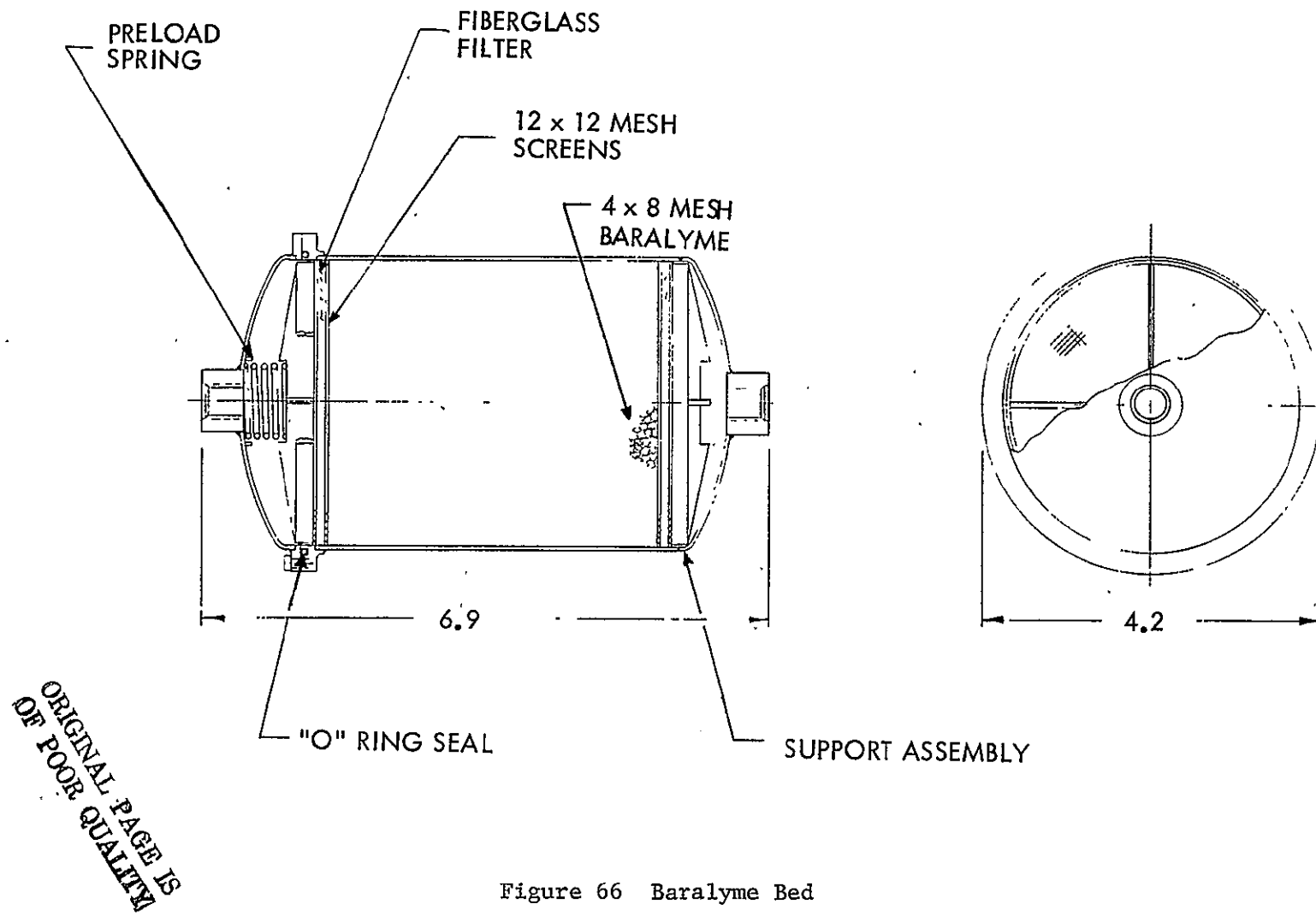
Carbon dioxide removal is accomplished by passing the oxygen stream over a chemical bed which absorbs the CO_2 . In this case granular baralyme is used as it works well in a saturated environment. The baralyme is contained in a canister which prevents leaks, provides the proper L/D for good removal efficiency, keeps the chemical firmly packed to prevent channeling, and filters the gas stream to prevent baralyme dust from leaving the bed. The unit is sized to provide CO_2 removal for 6 frogs for 12 days. Maximum CO_2 partial pressure in the gas at the bed exit is 4 mmHg after 12 days. During the rest of the mission it would be less.

As six frogs produce about 300 std cc CO_2 /hr and baralyme absorbs 0.503 lb CO_2 /lb baralyme, a twelve day mission requires 1.6 lb of baralyme at 50% utilization. This efficiency is consistent with maintaining 4 mmHg CO_2 partial pressure at the bed exit after 12 days.



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Figure 65 SCI-MED Kolobow Membrane Lung



176

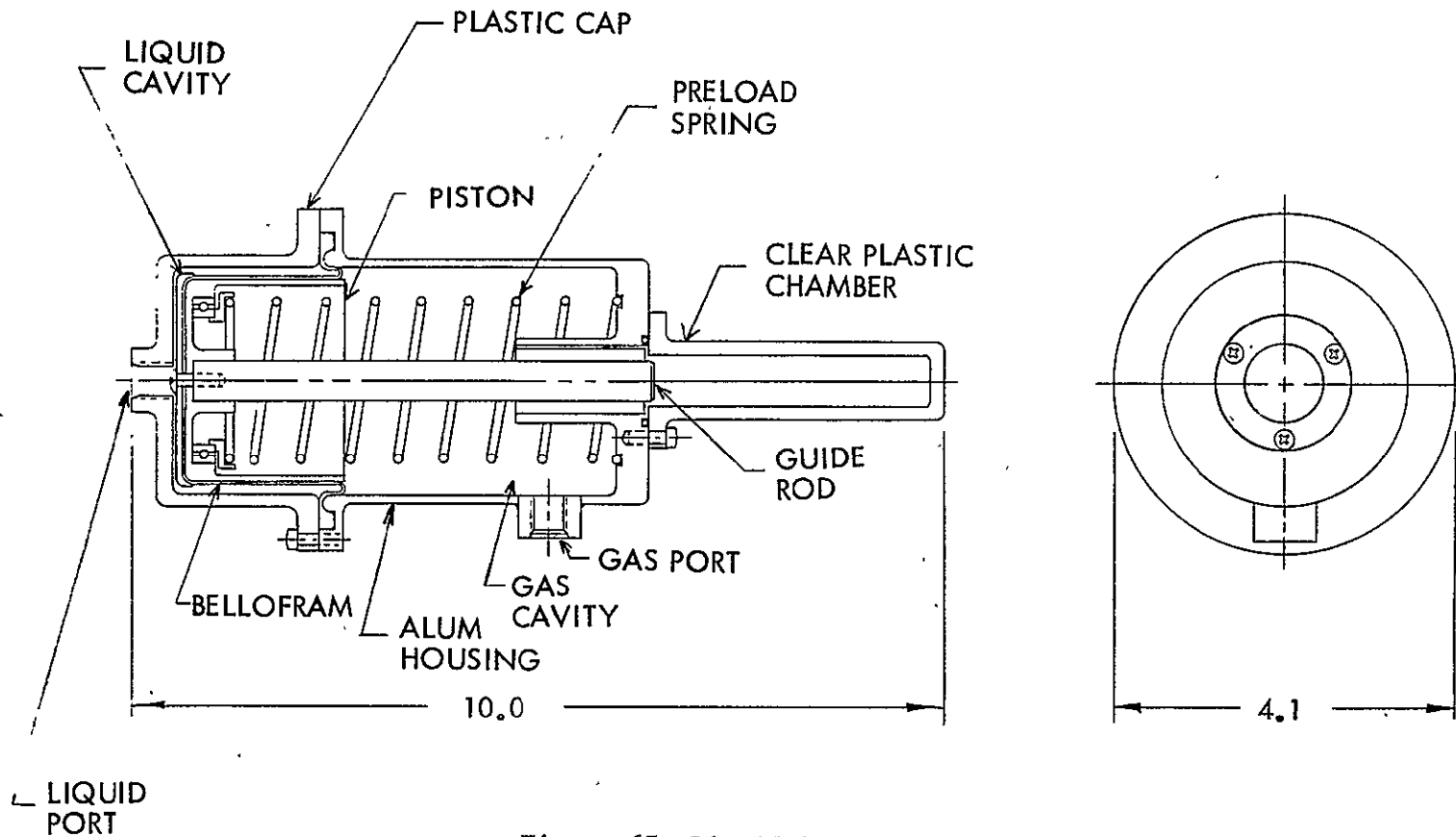


Figure 67 Liquid Accumulator

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serving the electrical isolation. The guide rod is rigidly attached to the piston and slides in a glass filled Teflon bearing in the case.

The liquid side cap is constructed of polycarbonate and has an AND 10050-4 boss. It attaches to the gas side housing with screws. The main body of the gas side housing is constructed of aluminum to conserve weight and is sealed to prevent gas leakage. An AND 10050-4 gas port is provided. The portion of the gas side housing which covers the guide rod is clear polycarbonate to allow the rod to be seen, as a visual quantity indicator. It is attached to the main body with screws, and an "O" ring seal is provided.

The preload spring is retained in a groove on the body end, and it fits into a retainer at the piston end. The retainer is mounted in a ball bearing to prevent torsion in the spring from affecting the bellofram. The spring is designed to provide about 0.5 to 1.5 psi liquid-gas pressure difference over the full range of the accumulator stroke.

The accumulator has a liquid volume of 16 cubic inches. The estimated liquid expansion of the whole system from 40-100°F is about 8 cubic inches. Therefore 8 cubic inches are available for leakage makeup or temperature excursions in excess of these temperatures.

The overall dimensions of the unit are 10 inches long and 4.1 inches in diameter.

Air Pump

The air pump is used to pump the oxygen and carbon dioxide mixture from the lung, through the baralyme canister, and back to the lung.

The chosen pump is a Brailsford and Company model TD-1A diaphragm pump. It is driven by a magnetically commutated brushless D.C. motor, directly mounted to the pumping section which consists of a molded plastic case containing a connecting rod-crank assembly, which drives a synthetic rubber dia-

phragm. Any gas being pumped comes in contact only with the plastic and synthetic rubber.

As shown in Figure 68, the pump has dimensions of $3 \frac{3}{8}$ " x $2 \frac{13}{16}$ " x $1 \frac{1}{2}$ " and weighs 0.6 pounds.

The pump operates on 18-28 volts and, as shown by Figure 68, produces a maximum of 3.1 liters per minute free flow at 24 VDC, and 1.3 liters per minute at 6 inches of mercury pressure drop. Model TD-1A is identical to model TD-2A shown in the curves, except that the stroke is completely adjustable from 0 to 100%. The unit has an operating life expectancy of 2500-5000 hrs.

In the VFR system the unit is expected to operate at less than 1 in Hg ΔP , and therefore, would consume about 2 watts of power at 28 VDC.

Circulating Pump

The circulating pump must deliver liquid at a rate of 500 cc/min to each frog canisters to carry oxygen to the frogs, remove carbon dioxide and keep the frogs cool. For six frogs this results in system flow of 0.8 gpm. A pressure drop analysis of the system shows a pump head of 13.2 psi is required.

The selected pump is a Micropump model 12-31-316. It is of the magnetically driven gear type, and has a 316 stainless steel housing, glass filled Teflon gears, and 28 VDC motor. The pump head is electrically isolated from the motor by the magnetic drive, non-metallic washer and non-metallic screws.

As shown in Figure 69, the unit has dimensions of 6.97" x 3.18" x 3.00" and weighs about 3 lbs.

The unit is capable of pumping the 0.79 gpm at 13.2 psi, and will consume about 25 watts under these conditions.

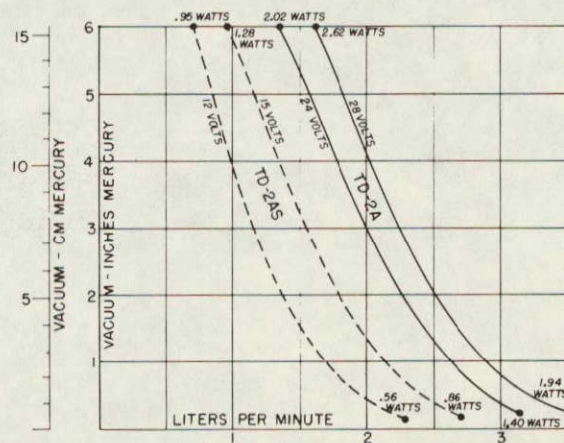
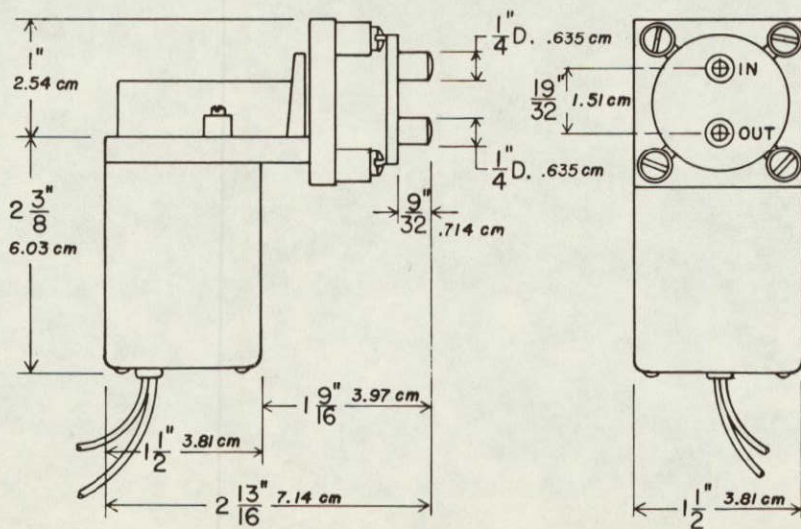
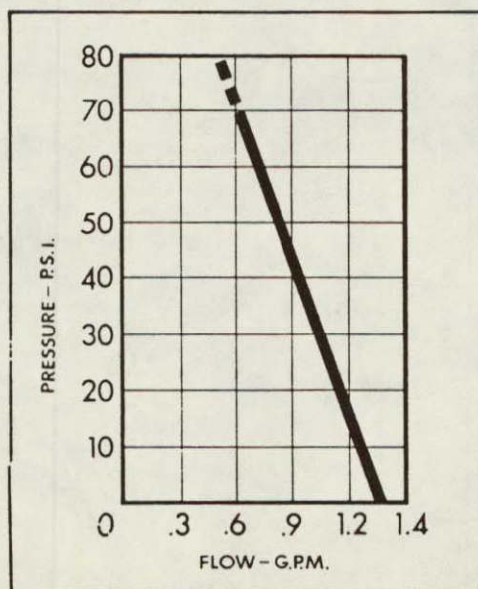
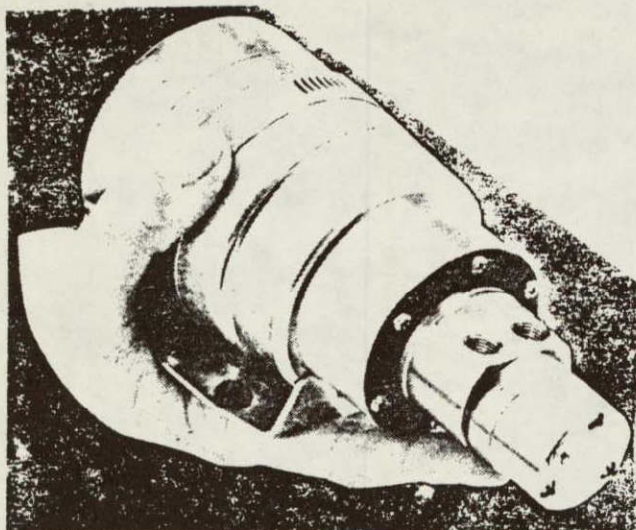


Figure 68 Air Pump

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PUMP

- 316 SERIES STAINLESS STEEL
- TEFLON AND FILLED TEFLON
- INTERNAL BY-PASS - ADJUSTABLE
- WEIGHT - PUMP/MOTOR - 3Lbs.

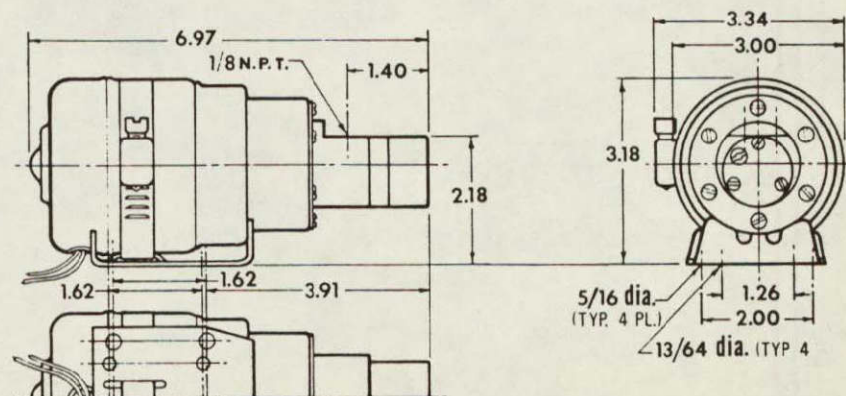


Figure 69 Circulation Pump

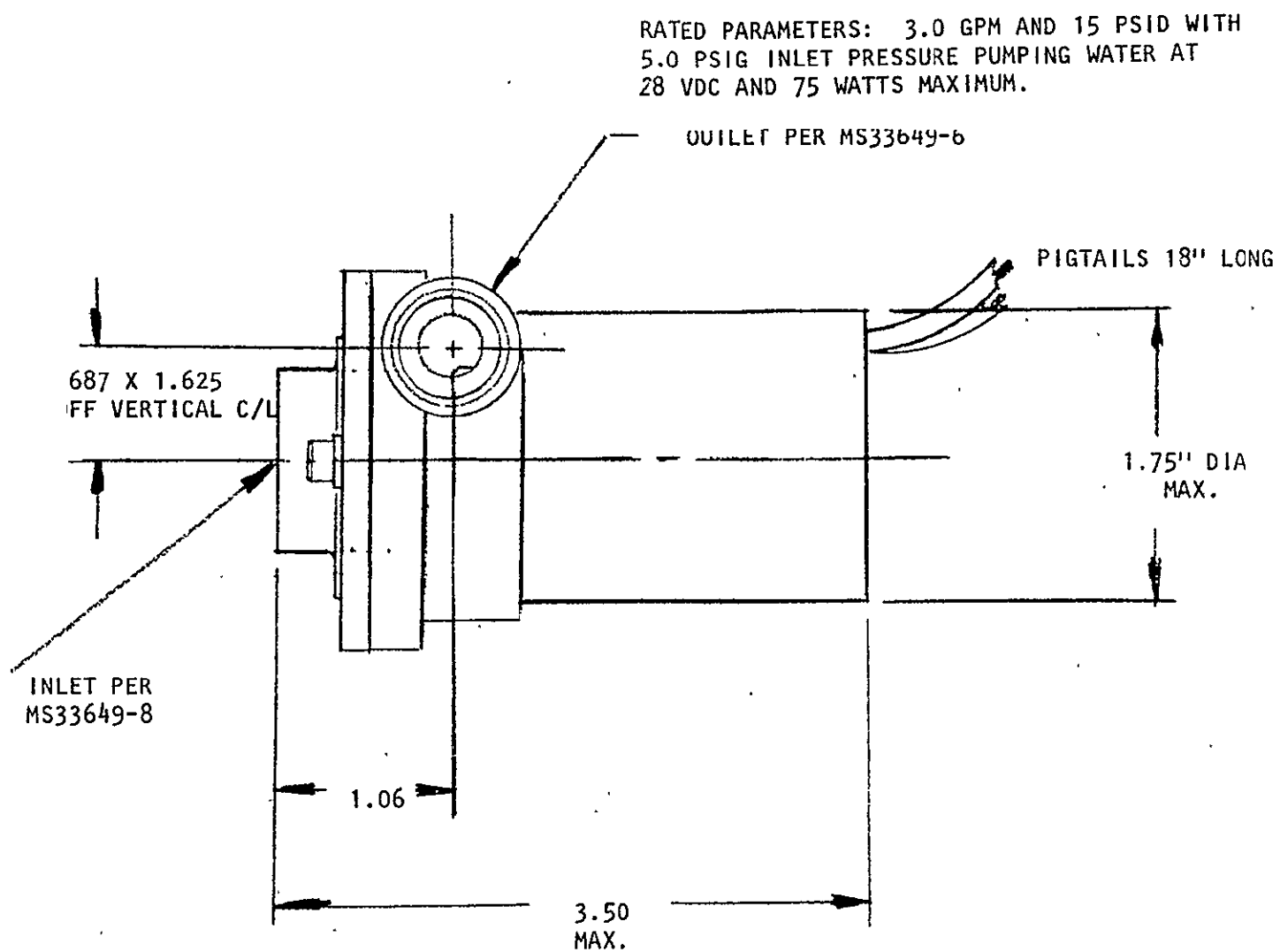


Figure 70 Wash Pump

As shown in Figure 71, the filter consists of a replaceable element and a housing. The element has an outer screen of 20 mesh stainless steel, and a pleated 40 micron inner screen with 100 in² of surface area. The screens are brazed between stainless steel sheet metal end caps. The inlet end of the element has a locating ring with four tabs, and the outlet end has a center guide and a surrounding rubber seal. The element is 2.4 inches in diameter and 4.8 inches in overall length.

The housing is constructed of .030 thick stainless steel and consists of a cylindrical portion with a torispherical end cap, and a cover portion, also with a torispherical end cap. All joints are welded. A bolted flange with an "O" ring seal is provided to join the two portions, thus allowing replacement of the element. AND 100050-6 inlet and outlet fittings are provided, and the overall dimensions are 6.4 inches long and 3.5 inches in diameter. The weight is 2.3 lbs.

The rubber seal between the cartridge and housing accommodates tolerance variations, allowing easy replacement of the cartridge, and prevents leakage between the inlet and outlet fluids.

During operation, water flows into the inlet end and passes through the slots in the locating ring, entering the space between the housing and cartridge. From here it flows through the coarse screen and the fine pleated element, into the center passage, and out through the outlet fitting.

Oxygen Pressure Regulator

The pressure regulator is used to reduce the high pressure oxygen to approximately 20 psia, the desired lung gas side pressure, thereby automatically supplying oxygen to the frog as required.

A Carlton Controls Model 1826001 absolute pressure regulator was selected to meet these requirements. It accepts inlet pressures from 3000 to 200

184

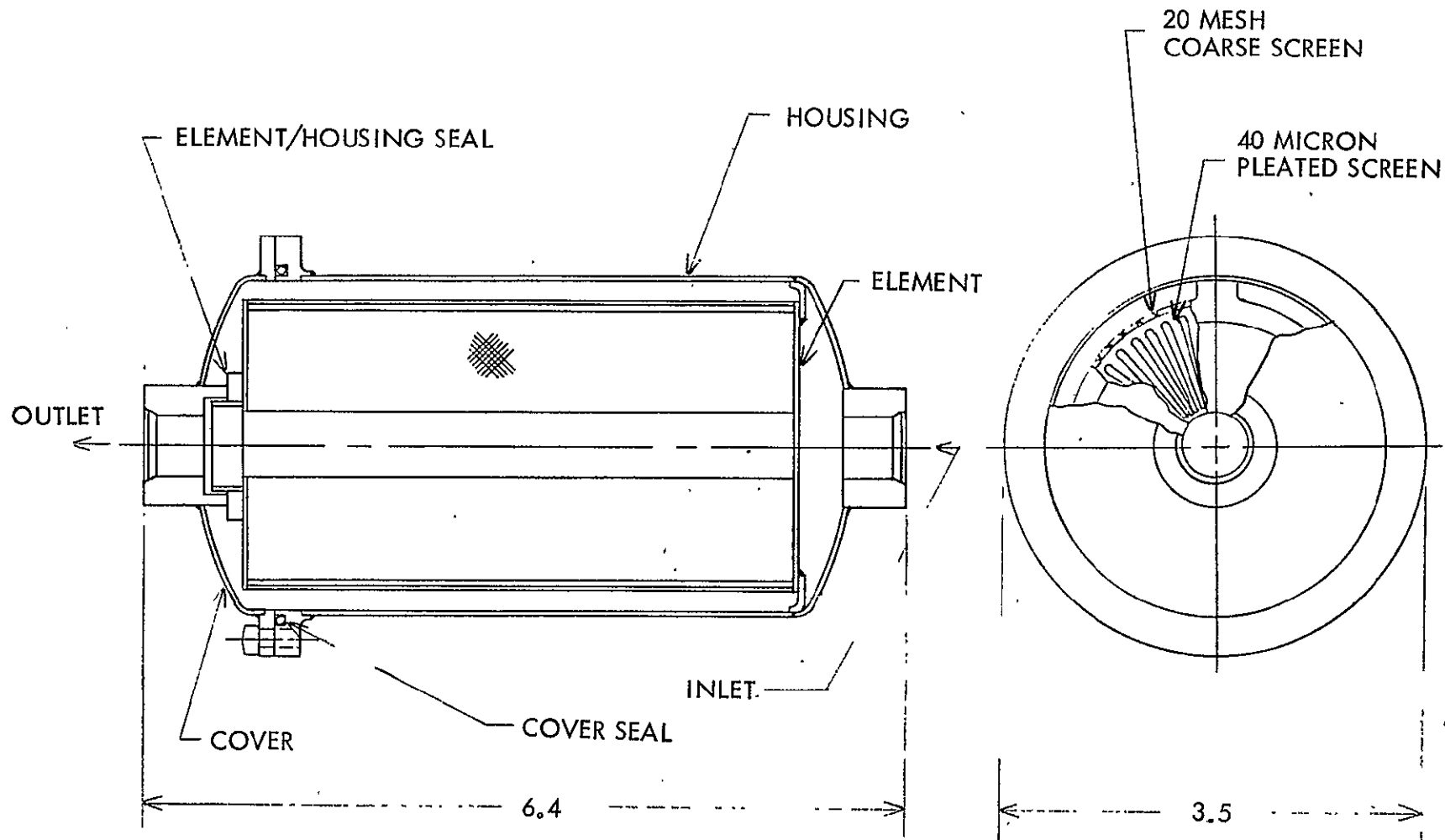


Figure 71 Filter

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psia and regulates to $20 \pm .5$ psia. It uses an aneroid bellows and spring to control a soft seat, thus regulating the oxygen flow. Maximum flow is 0.0416/hr.

The unit has MS24385-4 connections and is $3 \frac{19}{32}$ " x $2 \frac{5}{8}$ " x $2 \frac{13}{32}$ " in size. It weighs 0.7 pounds.

Water Tank

The water tank is used to add extra water to the system so that urea buildup can be properly controlled.

The tank is 5 inches in diameter and $13 \frac{1}{4}$ inches long. It has torispherical ends and is constructed of 0.03 inch thick stainless steel, and weighs 3.2 lbs. Two AND 100050-6 fittings are provided in one end of the tank. To insure mixing, a $\frac{3}{8}$ " diameter x 12" long dip tube is provided on the water inlet.

Oxygen Partial Pressure Sensor

The oxygen partial pressure sensor measures the dissolved oxygen in the water.

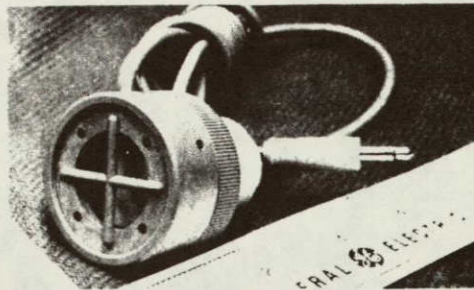
The selected sensor is manufactured by General Electric Co. and is a NASA qualified unit. It operates on a galvanic principle, converting chemical energy to electrical energy thus providing a direct measurement of the oxygen partial pressure. It has fairly low output impedance and can drive a meter directly. Other details are shown by Figure 72.

pH Sensor

The pH sensor measures the pH of the fluid returning to the canisters.

The selected sensor is designed for continuous monitoring (laboratory electrodes are not). It is a Presto-Tek Corporation Model 9037. This sensor utilizes the diffusion concept of reference electrode. It

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OPERATING CHARACTERISTICS

- Life. Operating capability equivalent to one year at sea level ambient conditions.
- Range. Provide accurate measurement of PO_2 over range of 0.1 to 1.2 atmospheres of oxygen.
- Output. 70 ± 10 millivolts at PO_2 of 1.0 atmosphere.
- Response. 90% of final value within 30 seconds of a step change in oxygen partial pressure.
- Accuracy. $\pm 2\%$ F.S., 0.1 to 0.4 atmosphere PO_2 ; $\pm 5\%$ of reading, 0.4 to 1 atmosphere PO_2 .
- Temperature. Range 40°F to 110°F
- Calibration. Stated accuracy of calibration is for any combination of operating temperature and pressure environments for the life of the sensor.

Figure 72 Oxygen Partial Pressure Sensor

Table 14 System Pressure Transducers

Item	Gould Statham Transducer #	Range (psi)	Basic Size (inches)	Weight (gm)
O ₂ tank pressure	PA 822	0-3000	1.01 dia x 1.83 lg	130
System liquid pressure	PA 822	0-15	" "	130
Circulating pump ΔP	PM 822	± 15	1.13 dia x 1.83 lg	130
Gas pump ΔP	PM 5TC	$\pm .15$	1.51 dia x 4.16 lg	310
TE fan ΔP	PM 5TC	$\pm .15$	" "	310
Filter ΔP	PM 732 TC	± 5	1.14 dia x 2.61 lg	200
Wash pump ΔP	PM 822	± 25	1.13 dia x 1.83 lg	130

Metal lines and fittings will be used where necessary or desirable. These will be of the MS flare type, and will be constructed of stainless steel.

Data System

The VFR flight data system preliminary design defined the measurements to be made and when they should be recorded or transmitted to ground, established data system interfaces and system operation during all mission phases, and described the hardware characteristics.

The Data System design was based upon the set of measurement and data acquisition requirements of Table 15. From the list, five data acquisition groups are defined. They are as follows:

Experiment Data - All data generated on the centrifuge from the specimens, instrumentation, and control equipment plus all house-keeping data generated by the Life Support System (LSS) and status data from the Data & Control Systems.

Control Data - All data generated by the control specimens plus control canister instrumentation.

Accelerometer Data - A subset of Experiment data consisting of the output signals from the three axis accelerometer mounted on specimen #1.

Houskeeping Data - A subset of Experiment data consisting of the data generated by the LSS plus selected status data from the Data and Control Systems.

Control Otolith Data - A subset of Control data consisting of the Otolith signals from the two control specimens.

Table 15 VFR Measurement and Data Acquisition Requirements

Definitions and Acquisition Period

<u>Abbreviation</u>	<u>Acquisition Period</u>
(P1 to KSC)	Transport from Pittsburgh (P.I. Facility) to KSC/MSOB
(MSOB to Load)	Transport from MSOB to loading platform
(Transfer)	Transfer to canisters from loading platform to spacelab
(Load to T ϕ)	From loading and initialization to launch (To)
(T ϕ to T1)	From launch (To) to T1 (orbit acquisition + 1st spin cycle + 10 min)
(T1 to T2)	From T1 to Spacelab activate (T2)
(T2 +)	After Spacelab activate
(Rec/4 Hrs)	Record data on board for post mission data correlation - 4 hours/mission

Definitions: Acquisition Mode

- A = Continuously
- B = Periodically - 15 minute intervals - 4 times/day
- C = Periodically - according to SOW timeline - ($\frac{1}{2}$ hour increments, 7 hours/day)
- D = Periodically - when other data is not required (1 hour/day)
- E = Via CDMS experiment computer status monitor loop

Definition: Primary Acquisition Method

- 1 Record analog
- 2 Record digital
- 3 Downlink

Table 15 (continued)

Acquisition/Period/Mode/Method

Measurement Description	Band- width (Hz)	Sample Rate S/Hz (min)	Range	Sensi- tivity	Accuracy	P1 to KSC	MSOB to Load	Transfer	Load to T ϕ	T ϕ to T1	T1 to T2	T2 + T2	Rec/4 Hrs.
Otolith, Left, Specimen 1	1800	5			$\pm 1\%$	B 1	B 1	-	B 1	A 1	C 1	C 3	1
Right	1												
Left	2												
Right	2												
Left	3												
Right	3												
Left	4												
Right	4											C 3	
Left	5											D 3	
Right	5												
Left	6												
Otolith, Right, Specimen 6	1800	5				B 1	B 1	-	B 1	A 1	C 1	D 3	1
EKG Specimen 1	1 200	4				B 2	B 2	-	B 2	A 2	C 2	C 3	2
2													
3													
4							B 2	-	B 2	A 2	C 2	C 3	2
5						-	-	-	-	-	-	D 3	-
EKG Specimen 6	200				$\pm 1\%$	-	-	-	-	-	-	D 3	-
Accel., X Axis, Specimen 1	250		± 1 g	.001 g			A 2	A 2	A 2	A 2	A 2	A 3	2
Y Specimen 1			± 1 g	.001 g									2
Accel., Z Axis, Specimen 1	250	4	± 1 g	.001 g		B 2	A 2	A 2	A 2	A 2	A 2	A 3	2
Accel., X Axis, Specimen 2	250	4	± 1 g	.001 g		B 2	B 2	A 2	B 2	A 2	C 2	C 3	2
Y	2												
Z	2												
X	3												
Y	3												
Accel., Z Axis, Specimen 3	250	4	± 1 g	.001 g		B 2	B 2	A 2	B 2	A 2	C 2	C 3	2

Table 15 (continued)

						Acquisition Period/Mode/Method								
Measurement Description	Band-Width (Hz)	Sample Rate S/Hz (min)	Range	Sensitivity	Accuracy	P1 to KSC	MSOB to Load	Transfer	Load to T Φ	T Φ to T1	T1 to T2	T2 +	Rec/4 hrs.	
Accel., X Axis, Specimen 4	250	4	± 1 g	.001 g		B 2	B 2	A 2	B 2	A 2	C 2	C 3	2	
Y	4													
Z	4								B 2	A 2	C 2	C 3	2	
X	5								-	-	-	D 3	-	
Y	5								-	-	-	-	-	
Z	5								-	-	-	-	-	
X	6								-	-	-	-	-	
Y	6								-	-	-	-	-	
Z Specimen 6	6							A 2	-	-	-	D 3	-	
X Canister 1								-	B 2	A 2	C 2	C 3	2	
Y Canister 1								-	-	-	-	-	-	
Z Canister 1	250		± 1 g	.001 g		B 2	B 2	-	-	-	-	-	-	
X Frame	600		± 5 g	.1 g		A 2	A 2	-	-	-	-	-	-	
Y Frame	600		± 5 g	.1 g		A 2	A 2	-	-	-	-	-	-	
Accel., Z Axis, Frame	600	4	± 5 g	.1 g		A 2	A 2	-	B 2	A 2	C 2	C 3	2	
Water Temp. Canister 1	.1	4	50-70°F	1°F		B 2	B 2	-	B 2	A 2	C 2	C 3	2	
2								-	-	-	-	-	-	
3								-	-	-	-	-	-	
4								-	-	-	-	C 3	-	
5								-	-	-	-	D 3/E	-	
Water Temp. Canister 6			50-70°F	1°F				-	-	-	-	D 3/E	-	
Pressure, O ₂ Tank			0-5000					-	-	-	-	C 3/E	-	
Δ P, Circulation Pump			± 15					-	-	-	-	-	-	
Pressure, System Liquid			0-15					-	-	-	-	-	-	
Δ P, Wash Pump			± 25					-	-	-	-	-	-	
Δ P, Gas Circul. Pump			$\pm .15$					-	-	-	-	-	-	
Δ P, Filter			± 5					-	-	-	-	-	-	
Δ P, Thermal Elec. Blower			$\pm .15$					-	-	-	-	-	-	
Temp. TE Unit Water Inlet				2°F				-	-	-	-	-	-	
Current, TE Unit								-	-	-	-	-	-	
Voltage, TE Unit								-	-	-	-	-	-	
pH, System Liquid	.1	4				B 2	B 2	-	B 2	A 2	C 2	C 3/E 2		

Table 15 (continued)

Measurement Description	Band- Width (Hz)	Sample Rate S/Hz (min)	Range	Sensi- tivity	Accuracy	P1 to KSC	MSOB to Load	Acquisition Period/Mode/Method					
								Transfer	Load to T ϕ	T ϕ to T1	T1 to T2	T2 +	Rec/4 Hrs.
PO ₂ , Canister 1	.1	4	500- 1200mmHg			B 2	B 2	-	B 2	A 2	C 2	C 3	2
2								-					
3								-					
4								-				C 3	
5												D 3	
PO ₂ , Canister 6	.1	4	500 1200mmHg			B 2	B 2	-	B 2	A 2	C 2	D 3	2
		Input For- mat	Sample Rate (S/Sec)	Range	Reso- lution (Time)	Digital Monitor Type							
Position, Tilt, Can. 1	8 Bit Parallel	562.5		2 ms	Bi-Level Status	-	-	-	-	-	C 2	C 3	2
2	" "					-	-	-	-	-			
3						-	-	-	-	-			
Position, Tilt, Can. 4	8 Bit Parallel				Bi-Level Status	-	-	-	-	-	C 2	C 3	2
Rate, Centrifuge Spin	8 Bit Serial	562.5		2 ms	Counter	-	-	-	-	-	C 2	C 3	2

Table 15 (continued)

Measurement Description	Band- Width (Hz)	Sample Rate	Range	Sensi- tivity	Monitor Type	Acquisition Period/Mode/Method						
						P1 to KSC	MSOB to Load	Transfer	Load to T ϕ	T ϕ to T1	T1 to T2	T2 + Rec/4 Hrs.
<u>Tape Recorder Monitors.</u>												
Record Indicator	.1		Rec/Off		Bi-Level	A	A	-	-	-	-	C 3/E -
Trouble Indicator	.1		Ok/Prob.		Bi-Level	A	A	-	-	-	-	-
Tape Remaining	.1		0-1 ma		Analog	A	A	-	-	-	-	C 3/E -
<u>Data & Control System Monitors</u>												
Voltage, System	.1		20-40V		Analog	-	-	-	B 2	B 2	A 2	C 3/E 2
Current, System	.1		0-20A		Analog	-	-	-	-	-	-	C 3/E 2
Control Bits Status					Bi-Level	-	-	-	B 2	B 2	A 2	C 3/E 2

Also from Table 15 we can define 3 data acquisition modes:

- o Record - Record data on VFR Experiment tape recorder
- o Downlink - Downlink via HRM and KUSP
- o CDMS status loop - monitor data by CDMS experiment computer

The CDMS status loop interfaces the entire housekeeping data group on demand and selected housekeeping parameters continually. It is operational at the time of Spacelab activate. The housekeeping data group interfaces CDMS via the Remote Acquisition Unit (RAU) flexible inputs where they are sampled and encoded and transmitted to the CDMS Experiment Computer for further processing. The other data groups interface with either the record or downlink acquisition mode or both as follows:

	Downlink	Record	Both
Experiment Data	X	X	X
Control Data	X		
Accelerometer Data	X	X	
Control Otolith Data		X	

These data groups however, do not require simultaneous interface to the data acquisition modes. The interface to the downlink is either experiment data, control data, or accelerometer data. The interface to the recorder is experiment data + control otolith data or accelerometer data. Combining the data groups with the data acquisition modes results in the generation of six distinct data control modes described in the following paragraphs.

Data System Operation

Figure 73 shows a typical data acquisition profile from system loading through Spacelab activation. Figure 74 is a block diagram of the VFR Data Acquisition System. The system operates in the following manner, referring to Figure 73. When the VFR experiment is initially loaded into

DATA CONTROL MODE

- ① RECORD ALL EXPERIMENT DATA + CONTROL OTOLITH DATA
- ② DOWNLINK EXPERIMENT DATA
- ③ ① AND ② COMBINED
- ④ DOWNLINK CONTROL DATA
- ⑤ DOWNLINK ACCELERATION DATA
- ⑥ RECORD ACCELERATION DATA

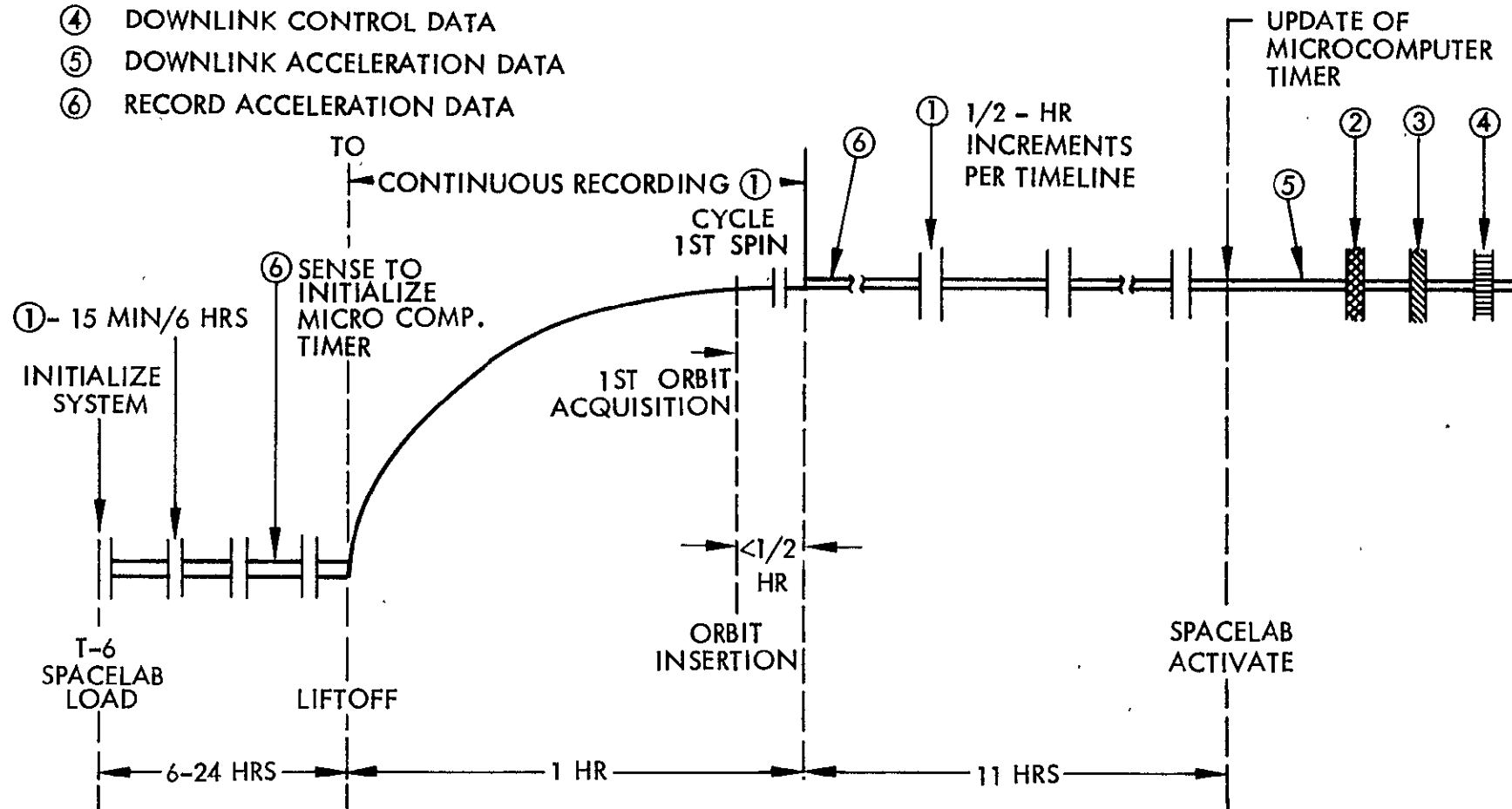


Figure 73 Data Acquisition Profile

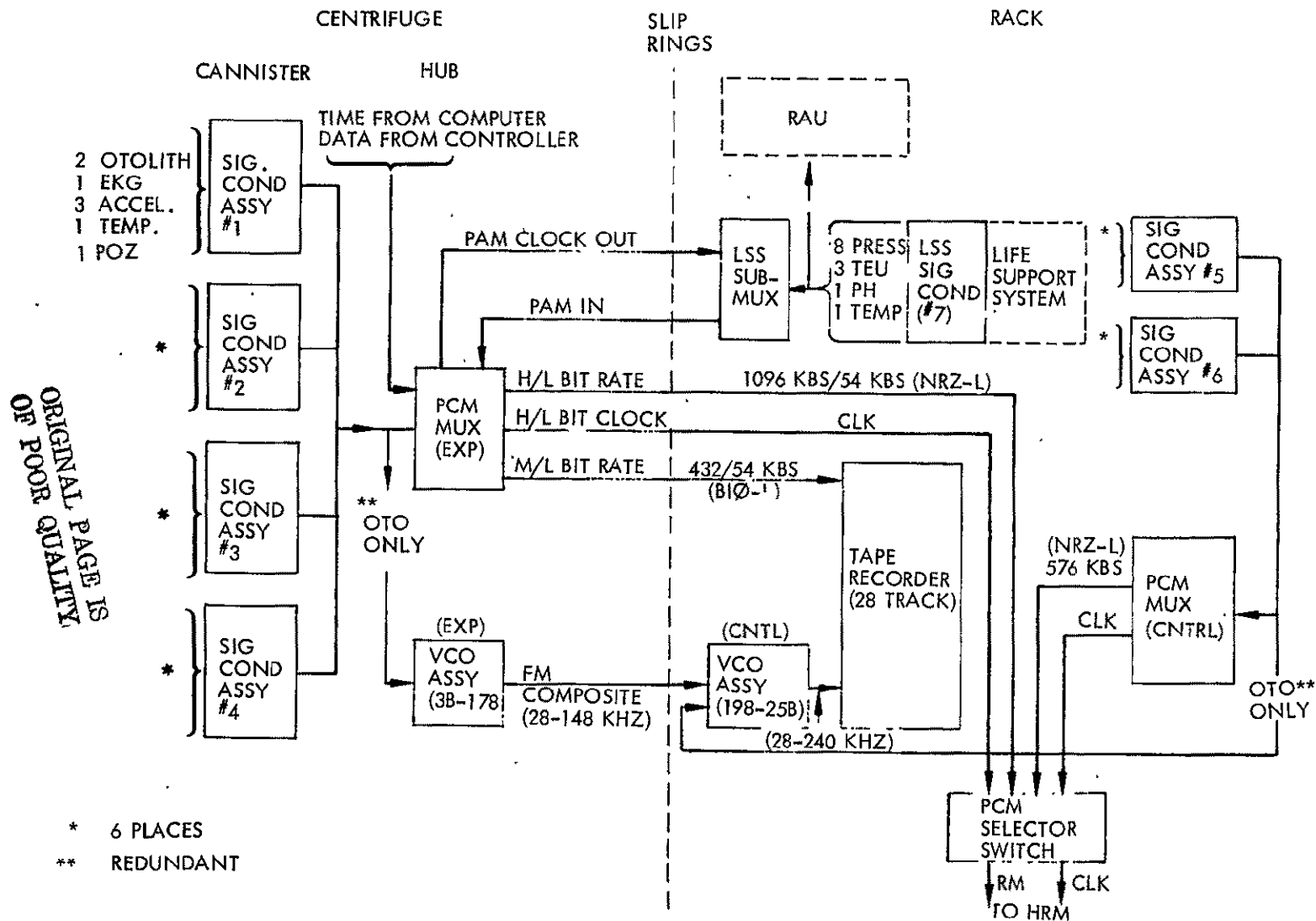


Figure 74 Data Acquisition System

Spacelab at T-6 the data system is initiated and controlled through the VFR microcomputer and experiment data + control. Otolith data is recorded on the VFR tape recorder (Data Control Mode 1) for 15 minute intervals every six hours until lift-off. All other times prior to lift-off, accelerometer data is continuously recorded. Referring to Figure 74 the operational sequence would be as follows: The experiment data is acquired via signal conditioning assemblies located on the centrifuge conisters, directly from the centrifuge and tilt controller (and from the LSS data submultiplexer located in the rack). This data is input to the experiment PCM multiplexer/encoder (PCM MUX) where it is sampled and encoded into a serial PCM bit stream. To output experiment data to the tape recorder, the PCM MUX recorder output is commanded to a medium bit rate. In this mode of operation, all input data except otolith data is multiplexed into the output bit stream, providing a 432 Kbs B1 $\emptyset$ -L signal into one channel of the tape recorder. The otolith data is routed to the experiment VCO assembly where, using constant bandwidth frequency modulation techniques, it is translated into a frequency division multiplex. The output of the experiment VCO assembly interfaces with the control VCO where the control otolith data are added to the frequency division multiplex. The composite output of the control VCO assembly is then input to Channel 2 of the VFR tape recorder. The VFR tape recorder is a 2P track direct record tape recorder that is used as a continuous 2 channel recorder by application of a built-in automatic bidirectional track sequencer.

The tape recorder is commanded to run at high speed - 30 inches per second (IPS) - decoding the experiment data and control otolith data (Data Control Mode 1) for 15 minutes. At the end of this interval the bit rate of the experiment PCM MUX is commanded to low (providing the accelerometer data at 54 Kbs-B1 $\emptyset$ -L) and the tape recorder speed is commanded to low (3 3/4 IPS) recording accelerometer data (Data Control Mode 6) on Channel 1 of the tape recorder for 6 hours or until lift-off

occurs. Lift-off initiation is sensed by a noise threshold sensor that provides a time zero (T0) indication to the VFR microcomputer. The microcomputer then initiates the appropriate commands so that Data Mode 1 is initiated and is maintained continuously through orbit acquisition and until 15 minutes after the first spin cycle is complete. This is controlled in the microcomputer by timing for a fixed interval from T0 and will occur within 1/2 hour of orbit acquisition. If orbit is not achieved for any reason a Safing Signal from the orbiter Caution and Warning System will be used to inhibit the microcomputer from initiating a centrifuge spin cycle. From then on, the data control mode alternates between 1 and 6 under direction of the microcomputer programs until such time that the Spacelab is activated and the Spacelab CDMS is operational. At that time the microcomputer timer is updated to be synchronous (± 1 second) with Event Time used in the CDMS Experiment computer via the CDMS Serial PCM command link through the RAU. After the timer is updated the accelerometer data interfaces with the downlink (Data Mode 5). In this mode the experiment PCM MUX downlink output is commanded to the low bit rate mode, providing the accelerometer data formatted in NRZ-L code at 54 KBS, as output along with a bit rate clock. The PCM Selector Switch is commanded to the normal position and the data is input to the CDMS High Rate Multiplexer (HRM).

From there it interfaces the downlink. Most of the time in orbit the VFR Data System will be in this mode of operation providing acceleration history data. The normal mode for acquisition of experiment data during orbit is Data Control Mode 2. In the 2 mode the experiment PCM MUX downlink output is commanded to high bit rate, providing all the experiment data, including otolith data to the HRM in NRZ-L code with the bit rate clock at a rate of 1,096 KBS. Control data is acquired in Data Mode 4. Here the Control PCM Multiplexer/Encoder is turned on and multiplexes and encodes data into a 576 KBS NRZ-L bit stream from the control specimen instrumentation that is conditioned in Signal Conditioner

assemblies 5 and 6. The PCM selector switch is commanded to the control position and the control data PCM and clock interface to the HRM for downlinking. Data mode 3 is used for recording experiment data on the VFR tape recorder while data is being downlinked. It is anticipated that this will be the major mode of acquiring recorded analog otolith data for post mission analysis and correlation. Data Mode 3 is implemented by commanding the Experiment PCM MUX recorder output bit rate to medium and the downlink output bit rate to high, the PCM selector switch being in normal position. The tape recorder has a capacity for fourteen hours of data at high speed and 112 hours at low speed. The data profile of Figure 73, using worst case times, would leave 5 hours at high speed for on orbit data recording after Spacelab activation. (The number of 14 track, 14 inch reels required on the ground to acquire the downlink data in a normal predetection record mode is approximately 20 for the entire mission).

Data System Control - Internal

Figure 75 shows the data system control implementation. All control is accomplished by 6 bits of information output from the VFR microcomputer. These bits are decoded in the centrifuge relay module and the rack relay module, opening or closing the appropriate relay contacts to produce the hardware control functions shown on Figure 75. The relay modules are part of the power control and distribution system. They turn power on and off to all of the data system equipment. They also provide signals to control the tape recorder speed, PCM MUX bit rates and PCM select switch position. The noise threshold sensor (for sensing lift-off), an acoustic pickup, is conditioned within the relay module, where the acoustic output is compared to a preset threshold level and integrated for a time period to insure the elimination of transient noise spikes before the $T = 0$ signal is sent to the microcomputer. When the microcomputer receives the $T = 0$ signal, Data Control Mode 1 is initiated.

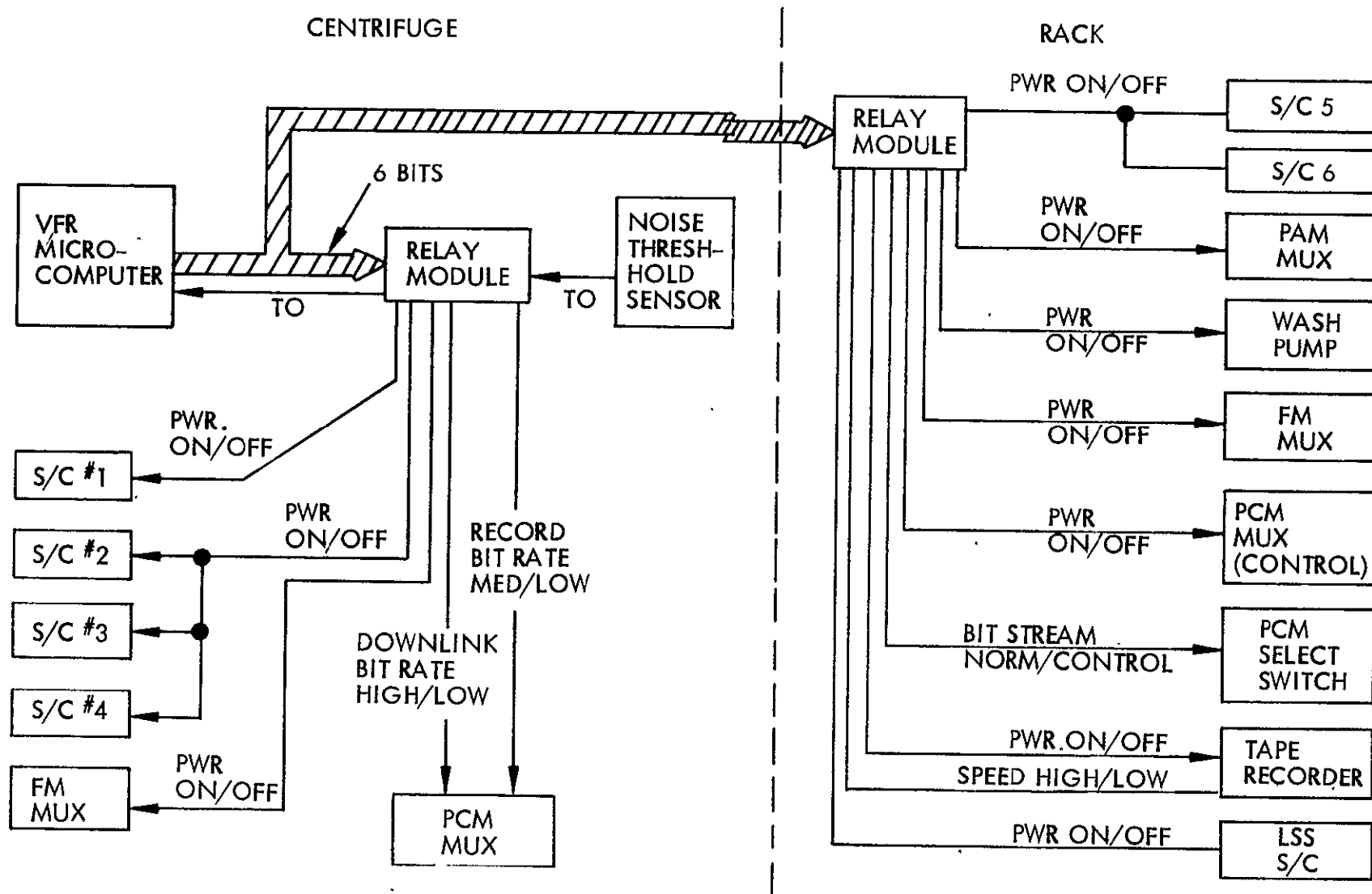


Figure 75 Data System Control

Figure 76 shows the utilization of the six control bits from the micro-computer. For Data Control Modes 1, 2 and 3, the last 4 bits are not decoded in the relay module but are interfaced directly to the appropriate signal conditioner assembly to control the gain of the EKG amplifiers. For Data Control Modes 4 and 6 the last bit is used in this manner to control the LSS wash pump. The last 2 bits for Data Control Mode 5, control EKG amplifier gain for the control specimens. Figure 77 shows the data equipment control matrix corresponding to the six data control modes.

Data System Control - External

The external control of the VFR experiment is limited to updating the programs stored in the VFR microcomputer. The external experiment control loop is shown in Figure 78. The safing command is used only during emergency de-orbit or initial orbit injection abort to prevent the centrifuge from spinning up. The MMU will be used to store an initial VFR microcomputer memory load, so that in the event of a software malfunction the VFR microcomputer can be loaded directly from the MMU, eliminating the need for a time consuming command uplink of the entire memory load. The primary use of the command uplink will be for program changes.

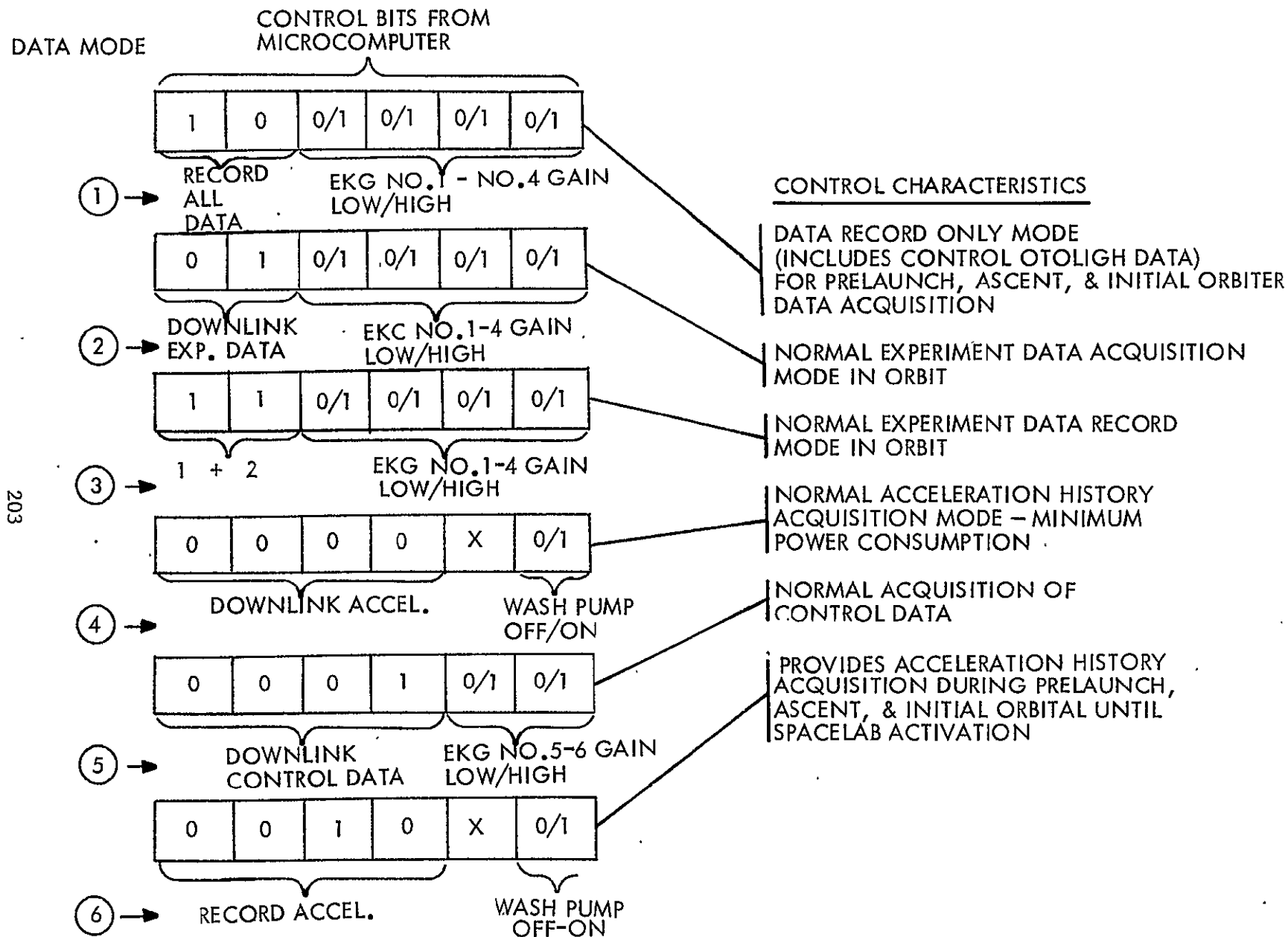


Figure 76 Data Control Mode Utilization

DUPLICATE FRAME

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DUPLICATE FRAME

2

EQUIPMENT FUNCTION																				
ON CENTRIFUGE																				
OFF CENTRIFUGE																				
DATA CONTROL MODE	CONTROL CODE						S/C 1 PWR	S/C 2 3, 4 PWR	VCO ASS'Y PWR	BIØ-L BIT RATE	NRZ-L BIT RATE	S/C 5, 6 PWR	CNTL PCM MUX PWR	CNTL VCO ASS'Y PWR	LSS SUB-MUX PWR	TAPE REC PWR	TAPE REC SPEED	PCM SEL. SW.POS.	LSS S/C	DATA CONTROL FUNCTION
①	1	0	X	X	X	X	ON	ON	ON	MED	X	ON	OFF	ON	ON	ON	HIGH	X	ON	RCD.ALL DATA
②	0	1	X	X	X	X	ON	ON	OFF	X	HIGH	OFF	OFF	OFF	ON	OFF	X	NORM	ON	DWNLK.EXP.DATA
③	1	1	X	X	X	X	ON	ON	ON	MED	HIGH	ON	OFF	ON	ON	ON	HIGH	NORM	ON	DWNLK.+ RCD
④	0	0	0	1	X	X	OFF	OFF	OFF	X	X	ON	ON	OFF	OFF	OFF	X	CONTROL	ON	DWNLK. CONT.DATA
⑤	0	0	0	0	X	X	ON	OFF	OFF	X	LOW	OFF	OFF	OFF	OFF	OFF	X	NORM	ON	DWNLK.ACCEL.DATA
⑥	0	0	1	0	X	X	ON	OFF	OFF	LOW	X	OFF	OFF	OFF	OFF	ON	LOW	X	OFF	RCD.ACCEL. DATA

Figure 77 Data Control Modes and Equipment Function

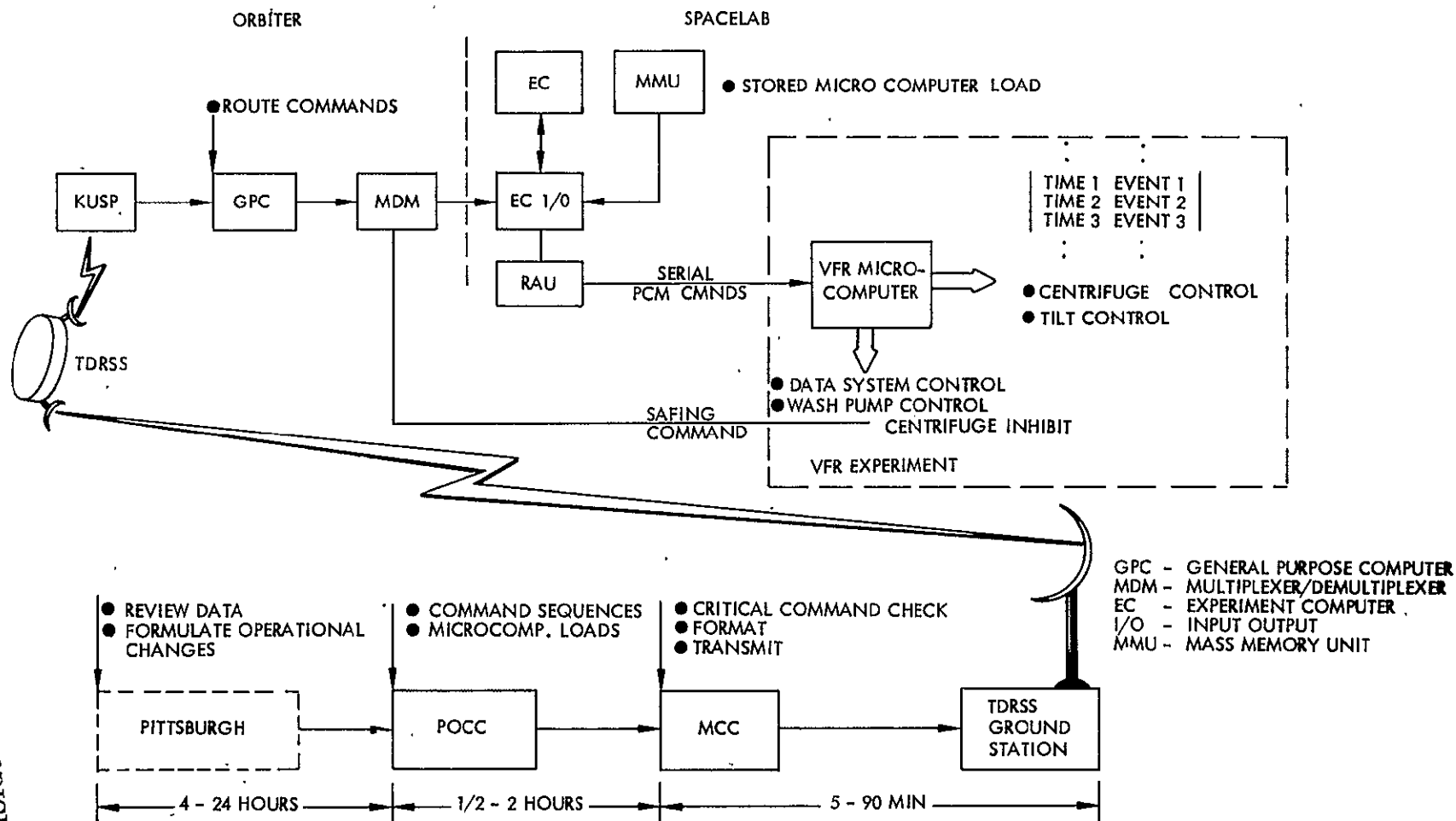


Figure 78 Experiment Data Control Loop

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VFR Data System Hardware

A summary of the description, function and operation of the various data system hardware components is given in Table 16. The majority of the components are buy items - some are off the shelf, requiring no engineering development effort. Design detail for each of the major components is contained in Figures 79 to 94.

CDMS to VFR Data System Interfaces

The VFR data system interfaces directly to an experiment data input channel of the CDMS High Rate Multiplexer. This interface is shown in Figures 4.2-1, 4.2-2 and Table 4.2-1 of SLP/2104 Appendix A. In addition, housekeeping data from the VFR data system interfaces to the flexible input channels of the RAU. This interface is shown in Figures 4.1-2, 4.1-4 and Table 4.1-5 of SLP/2104 Appendix A. There is one Caution and Warning System safing signal interface for centrifuge inhibit. This interface is made by hardwire to the orbiter MDM. The interface detail is shown in Figure 6-4 and Table 6-4 of SLP/2104 Appendix A.

Biological Data Grounding and Shielding

Common mode noise was a problem on otolith data collected during the OFO-A VFR experiment. It has been postulated that the cause of this noise was ground loops in the otolith electrode circuit. With the implanted electrode measuring essentially a common mode voltage, there was no effective way to reduce the common mode noise. The VFR canister design is such that it floats with respect to vehicle electrical ground. Care has been taken to insure that even the water interface through the life support system is ungrounded. In addition, each otolith amplifier excitation is individually transformer isolated and the PCM MUX input channel is differential, providing a unique measurement reference for each otolith electrode. Figure 94 shows a schematic of this configuration.

Table 16 Data System Hardware Summary

<u>Item</u>	<u>Quantity</u>	<u>Description</u>	<u>Make/Buy</u>	<u>Function and Operation</u>
1.	(6)	Bio Signal Conditioning System (See Figure 7 - 10)	Make	Each signal conditioning system consists of two electronic assemblies mounted on the canister and one multi-output isolated power supply mounted on the canister support arm. It conditions all signals originating in or on the canister.
2.	(1)	Life Support System Signal (See Figure 11)	Make	Located in the rack, it provides excitation and conditions for 8 pressure transducers, a pH sensor, a temperature monitor, and 3 thermal electric unit monitors. It provides dual outputs to the LSS data submultiplexer and to the remote acquisition unit. It also provides excitation and conditioning for the $\pm 5G$ triax accelerometer.
3.	(1)	Experiment PCM Multiplexer/Encoder (See Figure 12 - 15)	Buy	Located on the centrifuge hub it acquires data from all centrifuge canister signal conditioners as well as the external submux and centrifuge and tilt controller. Time is inserted into the output format from the microcomputer. It provides two outputs, one with a clock to interface the downlink via the high rate multiplexer, the other in self clocking format RI -L to interface with the experiment tape recorder.
4.	(1)	Centrifuge VCO Assembly (See Figure 16 and 18)	Buy	Multiplexes the otolith data from centrifuge mounted canisters by FM frequency division techniques. The VCO assembly contains 8 oscillators corresponding to IRIG constant bandwidth channels 3B-17B, and one reference oscillator at 240 KHz. One composite output

Table 16 (continued)

<u>Item</u>	<u>Quantity</u>	<u>Description</u>	<u>Make/Buy</u>	<u>Function and Operation</u>
				is provided through a modulation amplifier to interface with the experiment tape recorder via the control VCO assembly.
5.	(1)	Rack VCO Assembly (See Figure 17 and 18)	Buy	Multiplexes the otolith data from the rack mounted canister containing the control specimens by FM frequency division technique. The VCO assembly contains 4 oscillators corresponding to IRIG constant bandwidth channels 18B-25B. The outputs from these VC02 along with the composite output from the experiment VCO assembly are linearly mixed in a modulation amplifier that provides a single output to the tape recorder.
6.	(1)	LSS Data Submultiplexer (See Figure 19)	Buy	This is a 64 channel 2 line analog data multiplexer that accepts low level (0-50 mv) differential signals from the LSS pressure transducers and other sensors via the LSS signal conditioning. The output interfaces to the experimental PCM multiplexer/encoder via centrifuge slip rings.
7.	(1)	Control PCM Multiplexer/Encoder (See Figure 20)	Buy	Located in the rack its function is to multiplex and encode data from the control specimens mounted in canisters in the rack. Its input data interface are the canister signal conditioners. It provides one output with clock that interfaces to the downlink via the VFR PCM selector switch and High Rate Multiplexer.

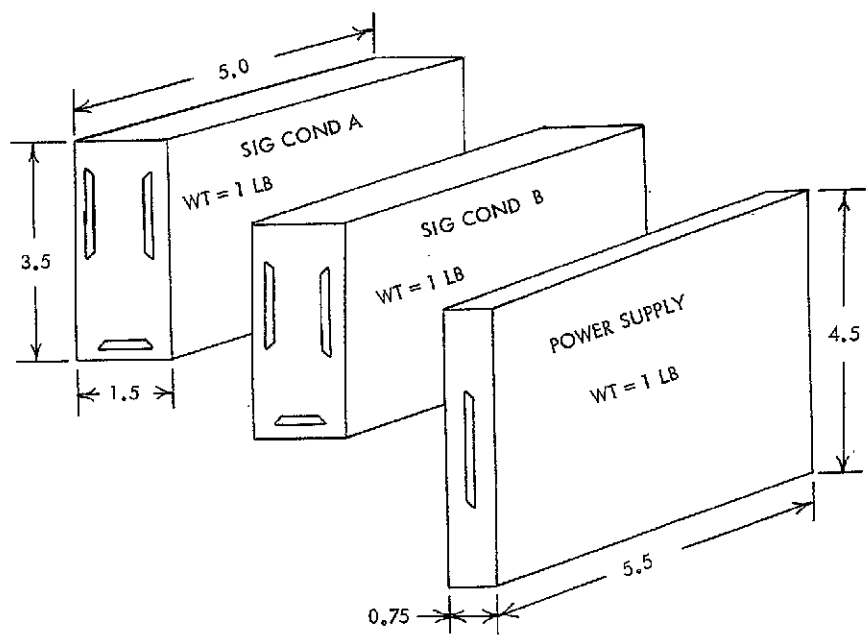
Table 16 (continued)

<u>Item</u>	<u>Quantity</u>		<u>Make/Buy</u>	<u>Function and Operation</u>
8.	(1)		Buy	Located in the rack, its function is to accept PCM data in BI -L code, and FM multiplex data and on command continuously record the input data until power is removed. This unit has 28 tracks that are used in a two channel sequential track switching configuration providing a total of 14 hours of recording time at a tape speed of 30 inches/second (IPS). A slow speed mode is also used (3 3/4 IPS) for recording acceleration history data.
9.	(1)	PCM Selector Switch (See Figure 22)	Make	Located in the rack, its function is to provide the proper PCM bit stream input to the HRM. On command it will switch between the control PCM bit stream and the experiment PCM.

SCHEMATIC DRAWING 1

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SCHEMATIC DRAWING 2



- PROVIDES CONDITIONING AND EXCITATION FOR SIGNALS FROM ONE CANNISTER
- EACH SIGNAL CONDITIONER CONTAINS 3 PC BOARDS
- SIGNAL CONDITIONER A INTERFACES
 - 2 OTOLITH SIGNALS, 1 EKG SIGNAL
 - 1 THERMISTOR, AND A PO2 SENSOR
- SIGNAL CONDITIONER B INTERFACES
 - 3 ACCELEROMETER SIGNALS
- THE POWER SUPPLY PROVIDES:
 - ONE $\pm 12V$ ISOLATED OUTPUTS
 - ONE $\pm 14V$ ISOLATED OUTPUT
 - ONE 15V ISOLATED OUTPUT

• 6 ASSEMBLIES REQUIRED

- 2 RACK MOUNTED
- 4 CENTRIFUGE/CANNISTER MOUNTED

• MOUNTING — ON CENTRIFUGE

SIGNAL CONDITIONER A AND B MOUNTED ON CANNISTER IN A BALANCED CONFIGURATION
POWER SUPPLIER MOUNTED ON CENTRIFUGE ARM NEAR CANNISTER MOUNT

• DESIGN

POWER SUPPLY — MODIFIED EXISTING DESIGN (SEE FIGURE)
OTOLITH AMPLIFIER — NASA SUPPLIED
EKG AMPLIFIER — NASA SUPPLIED
ACCELEROMETER CONDITIONING — SEPARATELY SHOWN
PO2 SENSOR — SEPARATELY SHOWN
THERMISTOR — SEPARATELY SHOWN

Figure 79 Biological Signal Conditioning Assembly

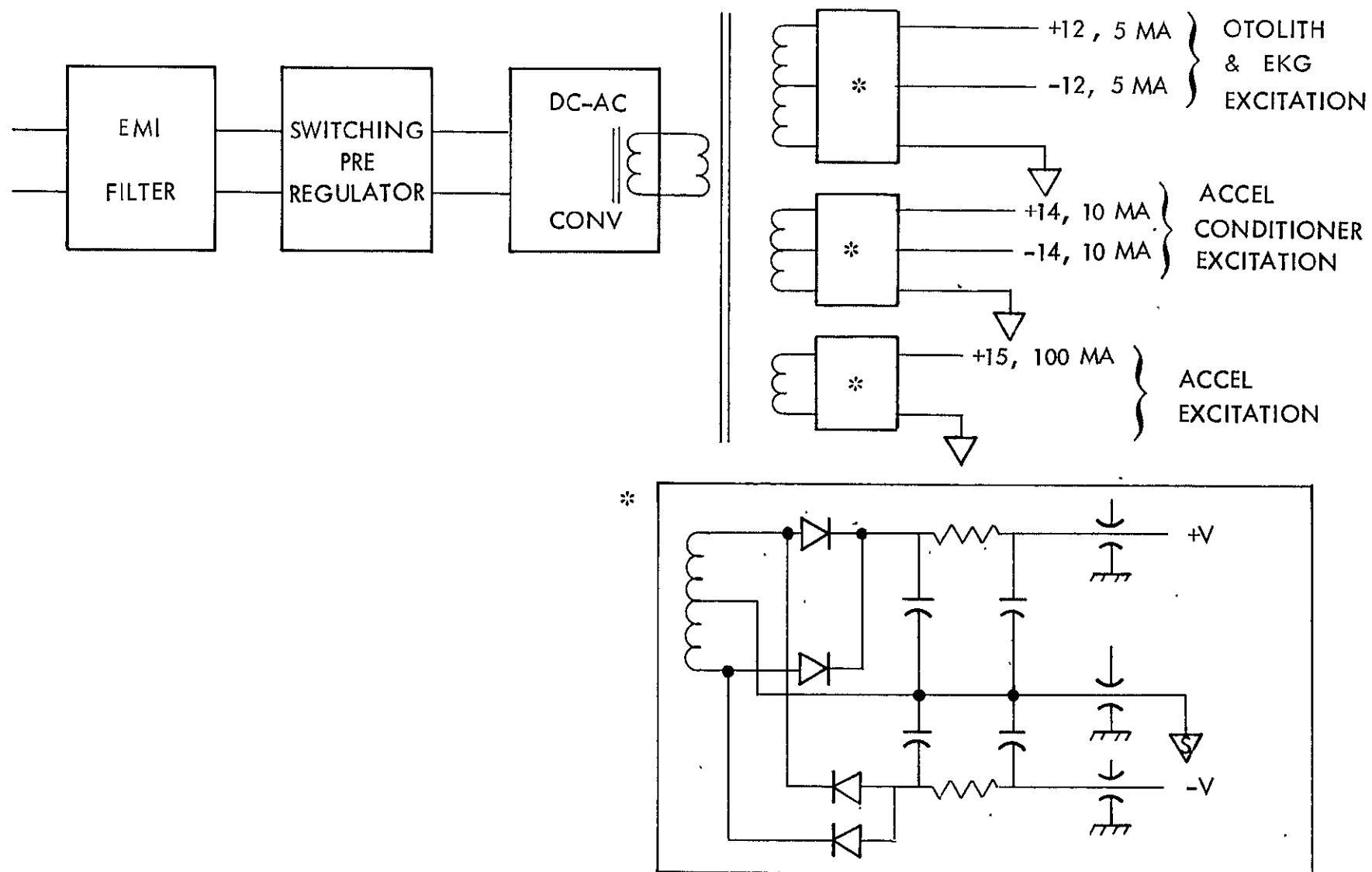


Figure 80 Bio-Signal Conditioning Power Supply

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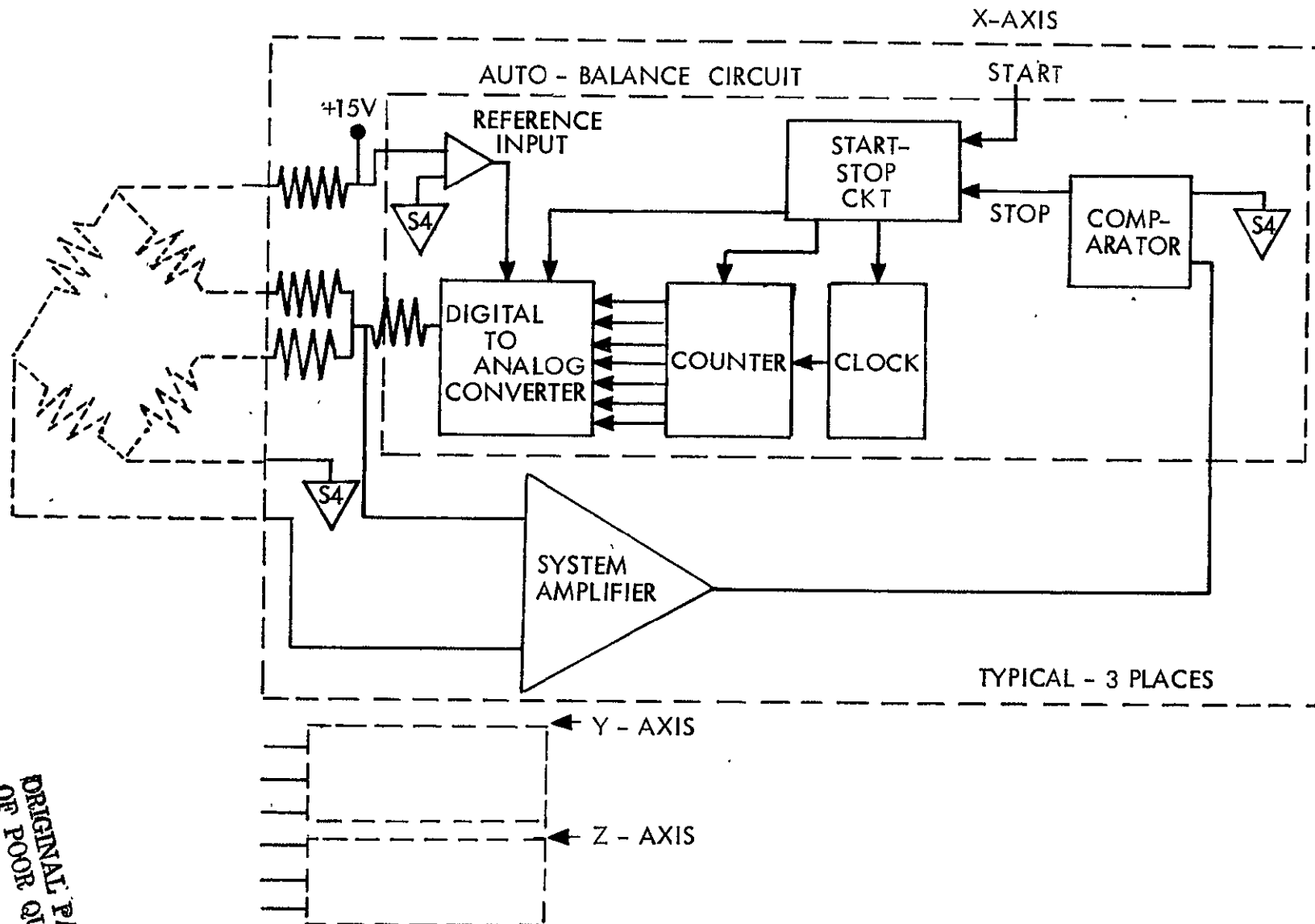


Figure 81 Accelerometer Signal Conditioning

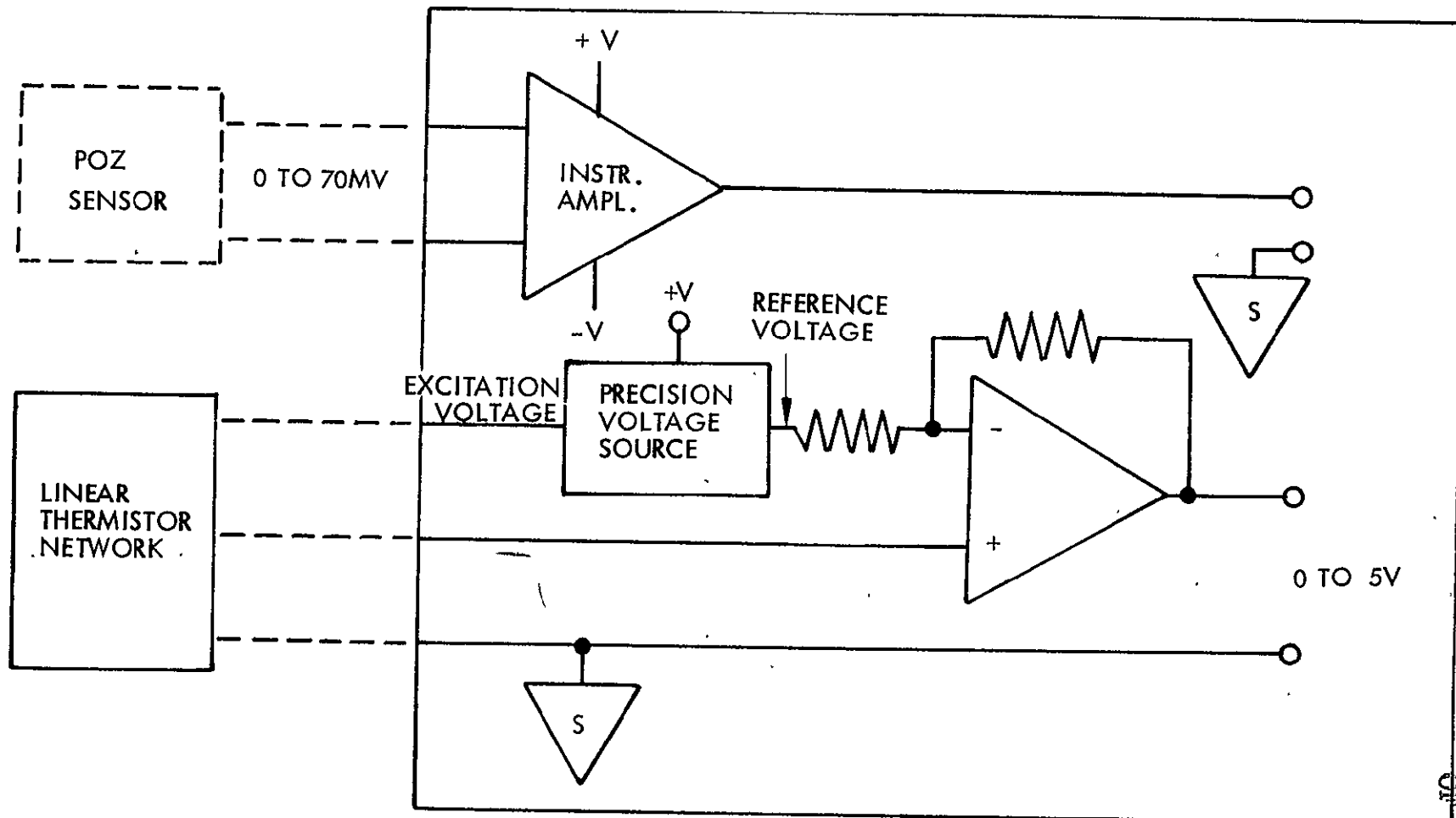
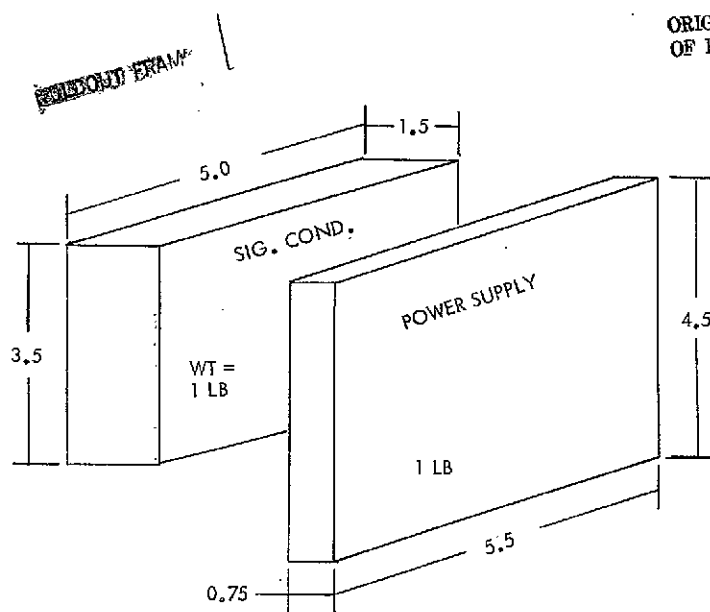


Figure 82 Temperature and PO₂ Signal Conditioning



- PROVIDES CONDITIONING & EXCITATION FOR ALL LSS INSTRUMENTATION & FOR ± 5 G ACCELEROMETER ON CENTRIFUGE FRAME
- POWER SUPPLY PROVIDES
 - ONE +10 VDC ISOLATED OUTPUT AT 200 ma
 - ONE +15 VDC ISOLATED OUTPUT AT 120 ma
 - ONE ± 14 VDC ISOLATED OUTPUT AT 10 ma

- ONE ASSEMBLY REQUIRED - RACK MOUNTED

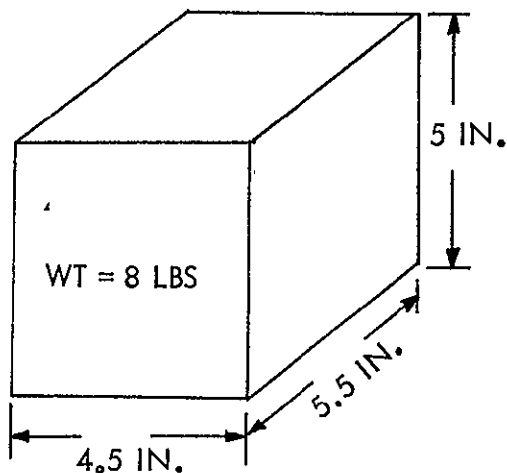
• SIGNAL CONDITIONING DESIGN

TE UNIT VOLTAGE - VOLTAGE PICK-OFF
 TE UNIT CURRENT - SHUNT
 TE UNIT INLET WATER TEMPERATURE - THERMISTOR COND. CRT
 ± 5 G ACCELEROMETER X AXIS-AMPLIFIER
 ± 5 G ACCELEROMETER Y AXIS-AMPLIFIER
 ± 5 G ACCELEROMETER Z AXIS-AMPLIFIER
 PH SENSOR-AMPLIFIER

• TRANSDUCER EXCITATION FOR

1 O₂ TANK PRESSURE AT 10 VDC, 28 ma
 1 CIRCULATION PUMP ΔP AT 10 VDC, 28 ma
 1 SYSTEM LIQUID PRESSURE AT 10 VDC, 28 ma
 1 GAS CIRCULATION PUMP PRESSURE AT 10 VDC, 28 ma
 1 FILTER ΔP AT 10 VDC, 28 ma
 1 TE BLOWER ΔP AT 10 VDC, 28 ma
 3 ACCELEROMETERS AT 15 VDC, 105 ma

Figure 83 LSS Signal Conditioner Assembly Features



- FLIGHT PROVEN COMPONENTS
- EXISTING DESIGN – MODIFIED
- LOW POWER CMOS LOGIC
- MOS FET ANALOG GATES
- POWER CONSUMPTION – 12 WATTS
- COMMANDABLE FORMATS

INPUTS

- 1 EXTERNAL PAM INPUT
64 CH x 8.79 HZ – CLOKOUT AT 562.5 HZ
- DIFFERENTIAL HIGH LEVEL ANALOG INPUTS
(01-09) 9 AT 9000 HZ – 8 BIT
- SINGLE ENDED HIGH LEVEL ANALOG INPUTS
 - ($V_1 - V_3$) 3 AT 4500 HZ – 8 BIT
 - ($A_1 - A_{16}$) 16 AT 1125 HZ – 12 BIT
 - ($E_1 - E_4$) 4 AT 1125 HZ – 8 BIT
 - ($L_1 - L_{32}$) 32 AT 17.58 HZ – 8 BIT
- 105 BIT LEVEL DIGITAL INPUTS
 - ($D_1 - D_{40}$) 40 AT 562.5 HZ – 1 BIT
 - ($B_1 - B_{64}$) 64 AT 140.625 HZ – 1 BIT
 - (C_1) 1 AT 562.5 HZ – 8 BIT (COUNTER)

Figure 84 Experiment PCM Multiplexer/Encoder

DO NOT SCALE

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OUTPUT NO. 1 TO DOWNLINK

S	S	S	01	02	03	04	05	06	07	08	09	A1	A2
												A3	A4
												A5	A6
												A7	A8
												A9	A10
												A11	A12
												A13	A14
												A15	A16

SEE
DETAIL
"A"

8
BIT

FORMAT A

12
BITS

120 x 1125 x 8
(80 x 1125 x 12)

CODE - NRZ-L WITH CLOCK

FRAME RATE = 1125 HZ

BIT RATE - HI = 1.094 MBS - FORMAT A

BIT RATE - LO = 0.054 MBS - FORMAT B

S	A1	A2	A3
---	----	----	----

4 x 1125 x 12

FORMAT B

OUTPUT NO. 2 TO TAPE RECORDER

CODE - B10-L

BIT RATE - MED. = 0.432 MBS - FORMAT C

BIT RATE - LO = 0.054 MBS - FORMAT B

FRAME RATE = 1125 HZ

FORMAT C

48 x 1125 x 8 (32 x 1125 x 12)

S	S	S	A1	A2
			A3	A4
			A5	A6
			A7	A8
			A9	A10
			A11	A12
			A13	A14
			A15	A16

8
BIT

12
BIT

S	A1	A2	A3
---	----	----	----

4 x 1125 x 12

FORMAT B

Figure 85 Experiment PCM Multiplexer/Encoder - Outputs

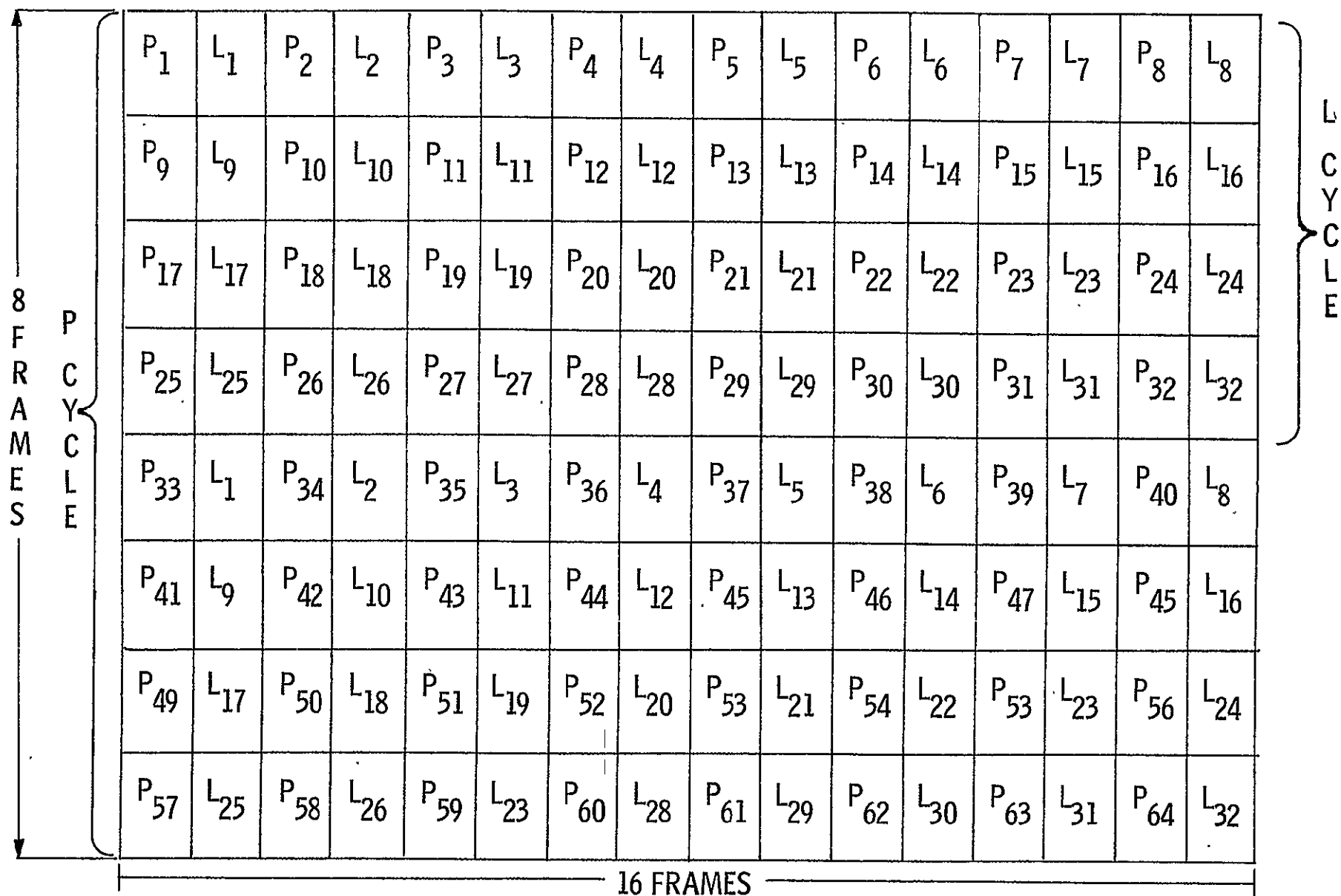
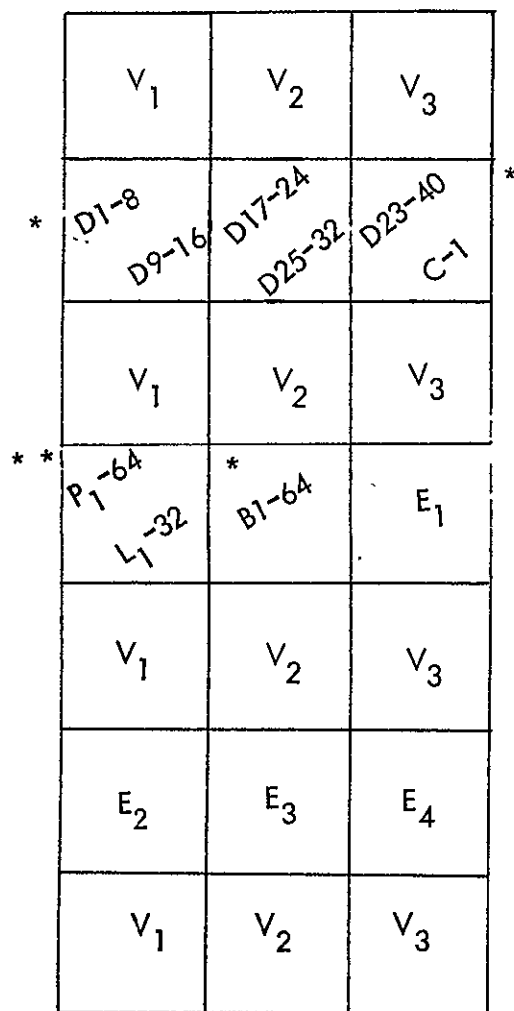
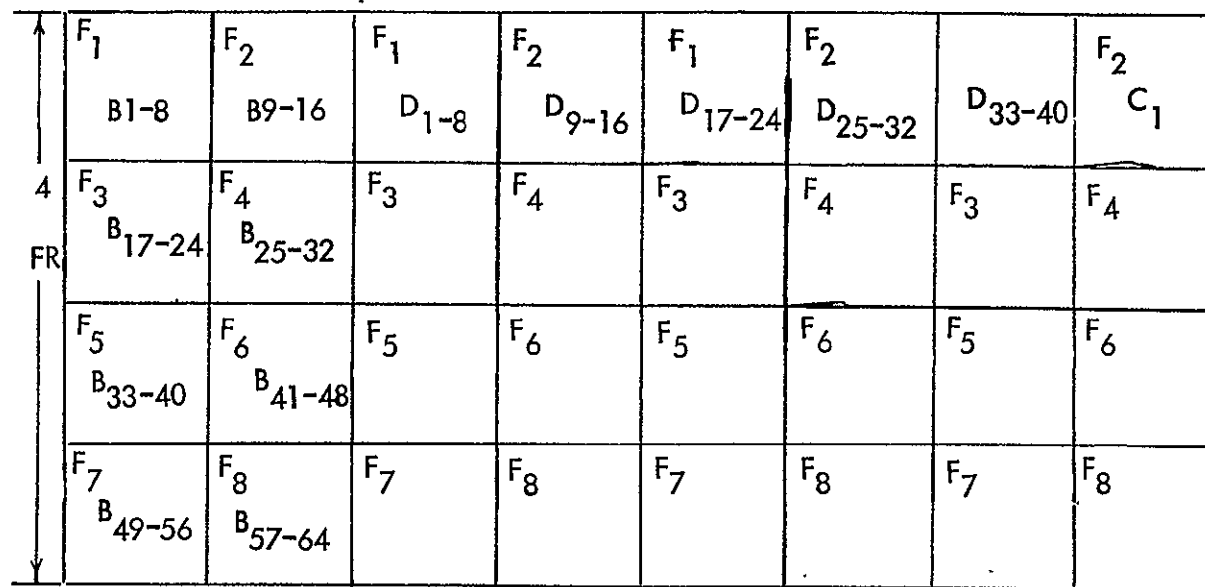


Figure 86 Format Detail Analog Data Cycle (128 Frames)



DETAIL "A"



28 FRAMES

* DIGITAL DATA (8 FRAMES) CYCLE

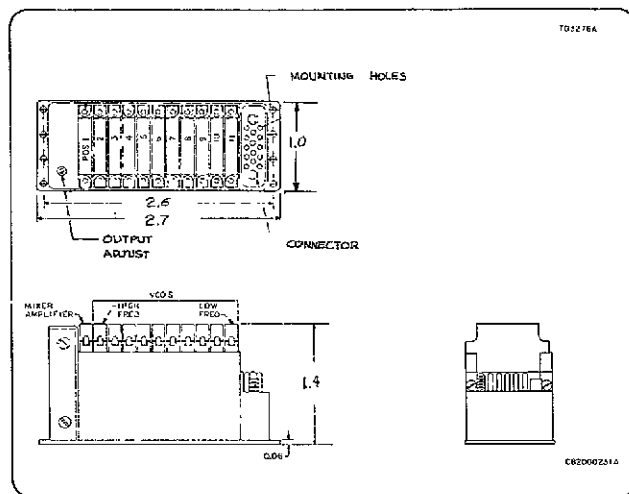
TIME CORRELATION

MISSION ELAPSED TIME IN SECONDS IS CONTAINED IN 24 BITS OF PARALLEL BINARY DATA FROM THE MICRO COMPUTER.

- UPDATED ONCE PER SECOND
- MONITORED ON BILEVEL INPUTS B_1 - B_{24}
- TIME OF UPDATE KNOWN WITHIN ± 4 ms

Figure 87 Experiment PCM MUX-Format Detail

~~FOLDOUT FRAME~~ /



- IRIG CONSTANT BANDWIDTH VCO's
- HIGH RELIABILITY - 2×10^6 MTBF
- THICKFILM TECHNOLOGY
- SPACE QUALIFIED DESIGN
- ENVIRONMENTALLY RUGGED
- EXTREMELY SMALL SIZE
- POWER CONSUMPTION < 2.1 WATTS

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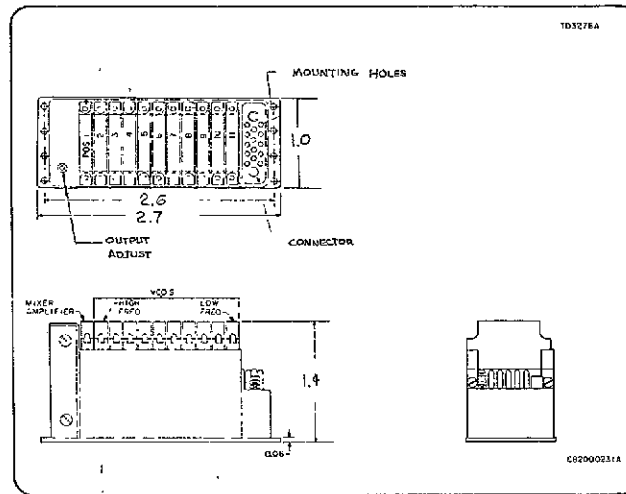
CONFIGURATION

- 8 CBW VCO's
- 1 MIXER AMPLIFIER

POSITION	1	2	3	4	5	6	7	8	9
COMPONENT	MIXER AMP	C H	C H	C H	C H	C H	C H	C H	C H
		17 B	15 B	13 B	11 B	9 B	7 B	5 B	3 B
		V C O	V C O	V C O	V C O	V C O	V C O	V C O	V C O
CENTER FREQUENCY (KHZ)		144	128	112	96	80	64	48	32
DEVIATION (KHZ)		±4	±4	±4	±4	±4	±4	±4	±4

- VCO INPUT LEVEL - 0 TO 5 VOLTS
- EXCITATION - 28 ± 4 VOLTS DC
- SEE FIG. 18 FOR SIGNAL ASSIGNMENT

Figure 88 Centrifuge VCO Assembly Features



- IRIG CONSTANT BANDWIDTH VCO's
- HIGH RELIABILITY -2×10^6 MTBF
- THICKFILM TECHNOLOGY
- SPACE QUALIFIED DESIGN
- ENVIRONMENTALLY RUGGED
- EXTREMELY SMALL SIZE
- POWER CONSUMPTION < 2.1 WATTS

CONFIGURATION

- 4 CBW VCO's
- 1 MIXER AMPLIFIER
- 1 INTERFACE MODULE
- 1 REFERENCE OSCILLATOR

POSITION	1	2	3	4	5	6	7
COMPONENT	M I X E R A M P	R E F O S C	C H 25 B V C O	C H 23 B V C O	C H 21 B V C O	C H 19 B V C O	I N T E R F A C E
CENTER FREQUENCY (KHZ)		240	208	192	176	160	
DEVIATION (KHZ)			± 4	± 4	± 4	± 4	

- VCO INPUT LEVEL 0 TO 5 VOLTS
- EXCITATION $- 28 \pm 4$ VOLTS DC
- SEE FIG. 18 FOR SIGNAL ASSIGNMENT

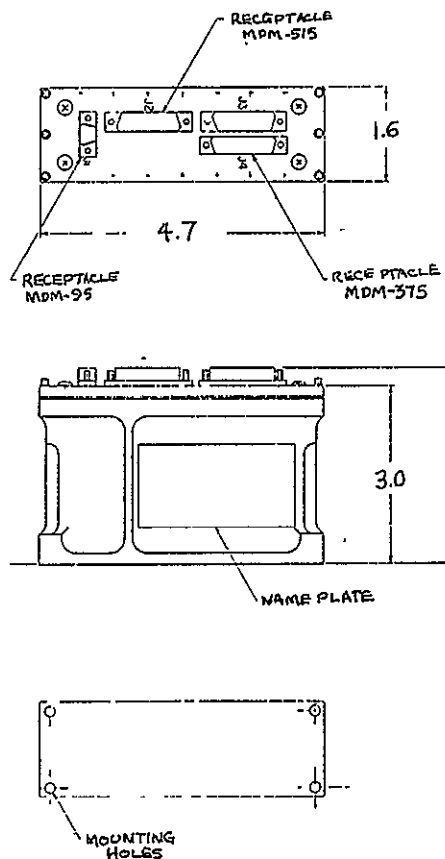
Figure 89 Rack VCO Assembly

FIGURE 90 VCO ASSIGNMENT

<u>CHANNEL</u>	<u>CENTR FREQ</u>	<u>DEV LIMITS</u>	<u>ASSIGNMENT</u>
3 B	32 KHZ	± 4 KHZ	-L-OTO #1 On Cent.
5 B	48 KHZ	± 4 KHZ	-R-OTO #1 On Cent.
7 B	64 KHZ	± 4 KHZ	-L-OTO #2 On Cent.
9 B	80 KHZ	± 4 KHZ	-R-OTO #2 On Cent.
11 B	96 KHZ	± 4 KHZ	L-OTO #3 On Cent.
13 B	112 KHZ	± 4 KHZ	R-OTO #3 On Cent.
15 B	128 KHZ	± 4 KHZ	L-OTO #4 On Cent.
17 B	144 KHZ	± 4 KHZ	R-OTO #4 On Cent.
19 B	160 KHZ	± 4 KHZ	L-OTO #5 Control
21 B	176 KHZ	± 4 KHZ	R-OTO #5 Control
23 B *	192 KHZ	± 4 KHZ	L-OTO #6 Control
25 B *	208 KHZ	± 4 KHZ	R-OTO #6 Control
Ref. Osc.	240 KHZ		

* Non Standard

222



- EXISTING DESIGN
- FLIGHT PROVEN
- MOSFET ANALOG GATES
- POWER CONSUMPTION 2.5 WATTS
- WT = 21 OUNCES

INPUTS

64 DIFFERENTIAL LOW LEVEL ANALOG INPUTS—

64 AT 8.79 HZ - 0 TO 50 mV.

1 CLOCK SIGNAL AT 562.5 HZ SQUARE WAVE
WITH NEGATIVE RESET PULSE

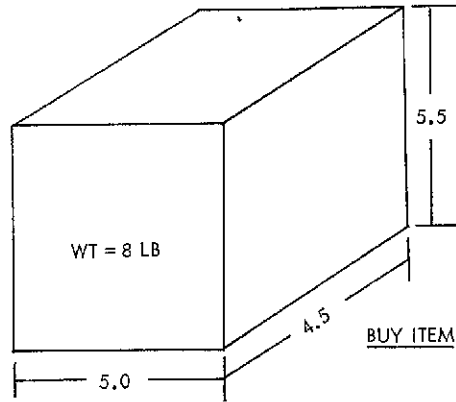
OUTPUT

1 PULSE AMPLITUDE MODULATED SIGNAL

1 AT 562.5 SAMPLES/SECOND

Figure 91 Life Support System Data Submultiplexer

FOLDOUT FRAME 1



- EXISTING DESIGN - MODIFIED
- MOSFET ANALOG GATES
- POWER CONSUMPTION - 12 WATTS
- PROM FORMATTER
- FLIGHT PROVEN COMPONENTS

TIME CORRELATION :

SINCE THIS FORMAT IS USED.
ONLY FOR DOWNLINK, TIME
CORRELATION WILL BE TO THE
GMT CONTAINED WITHIN THE
HRM FORMAT

SIGNAL CHARACTERISTICS

- $O_1 - O_4$ 4 AT 9000 HZ - 8 BIT 0-5 V
- $A_1 - A_6$ 6 AT 1500 HZ - 12 BIT 0-5 V
- $E_1 - E_9$ 10 AT 1500 HZ - 8 BIT 0-5 V
- $L_1 - L_{32}$ 32 AT 46.875 HZ - 8 BIT 0-5 V
- 32 BIT LEVEL SINGLE ENDED DIGITAL INPUTS
- $B_1 - B_{32}$ 32 AT 375 HZ - 1 BIT 0-5 V

OUTPUT

CODE - NRZ-L WITH CLOCK

BIT RATE - 0.576 MBS

FRAME RATE - 1500 HZ

FORMAT: $48 \times 1500 \times 8$ ($32 \times 1500 \times 12$)

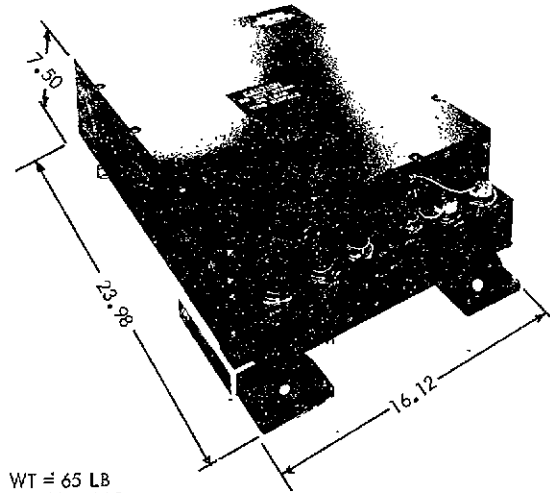
S	S	S	FID	O_1	O_2	O_3	O_4
F_1	A_1		A_2				
E_2	E_3	E_4	E_5				
A_3	A_4	E_6					
E_7	A_5	A_6					
E_8	E_9	L_{1-32}	B_{1-32}	▼	▼	▼	▼

S	S	S	FID	O_1	O_2
O_3	O_4	E_1	A_1		A_2
O_1	O_2	O_3	O_4	F_2	F_3
E_4	E_5	O_1	O_2	O_3	O_4
A_3		A_4	E_6	O_1	O_2
O_3	O_4	E_7	A_5		A_6
O_1	O_2	O_3	O_4	E_8	E_9
E_{10}	B_{1-32}	O_1	O_2	O_3	O_4

Figure 92 - Control PCM Multiplexer/Encoder Features

ENCLOSURE 1

ENCLOSURE 2

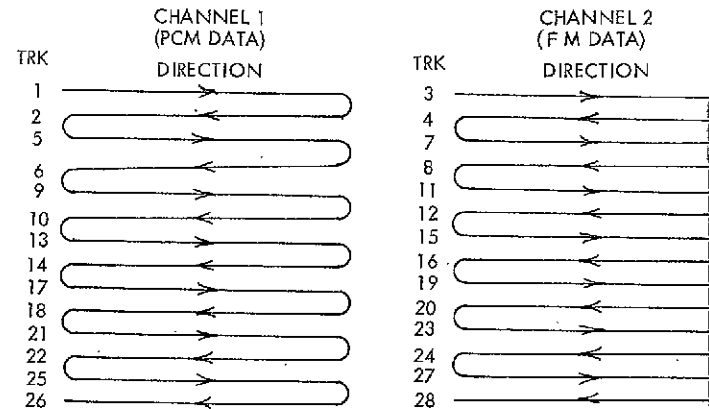


WT = 65 LB
INCLUDING
TAPE

- MARS 1400 LT-3 SERIES
- SPACE QUALIFIED
- BEING USED BY NAR ON ORBITER
- 14 INCH REEL
- 1 INCH MYLAR TAPE (9200 FT)
- 6 TAPE SPEEDS AVAILABLE
- AUTOMATIC BI-DIRECTIONAL TRACK SEQUENCING
- TAPE CHANGE DURING MISSION NOT REQUIRED

CONFIGURATION

- DIRECT RECORD ONLY
- 28-TRACK ONE INCH TAPE FORMAT
- 2 INPUT CHANNELS AUTOMATICALLY SEQUENCED OVER 28 TRACKS IN BI-DIRECTIONAL MODE



- 2 SELECTABLE SPEEDS ON COMMAND
 - 30 IPS - NORMAL RECORD MODE
 - 3-3/4 - ACCELEROMETER RECORD MODE
- RECORD TIME
 - 30 IPS - 14 HOURS
 - 3-3/4 IPS - 112 HOURS

Figure 93 VFR Tape Recorder Features

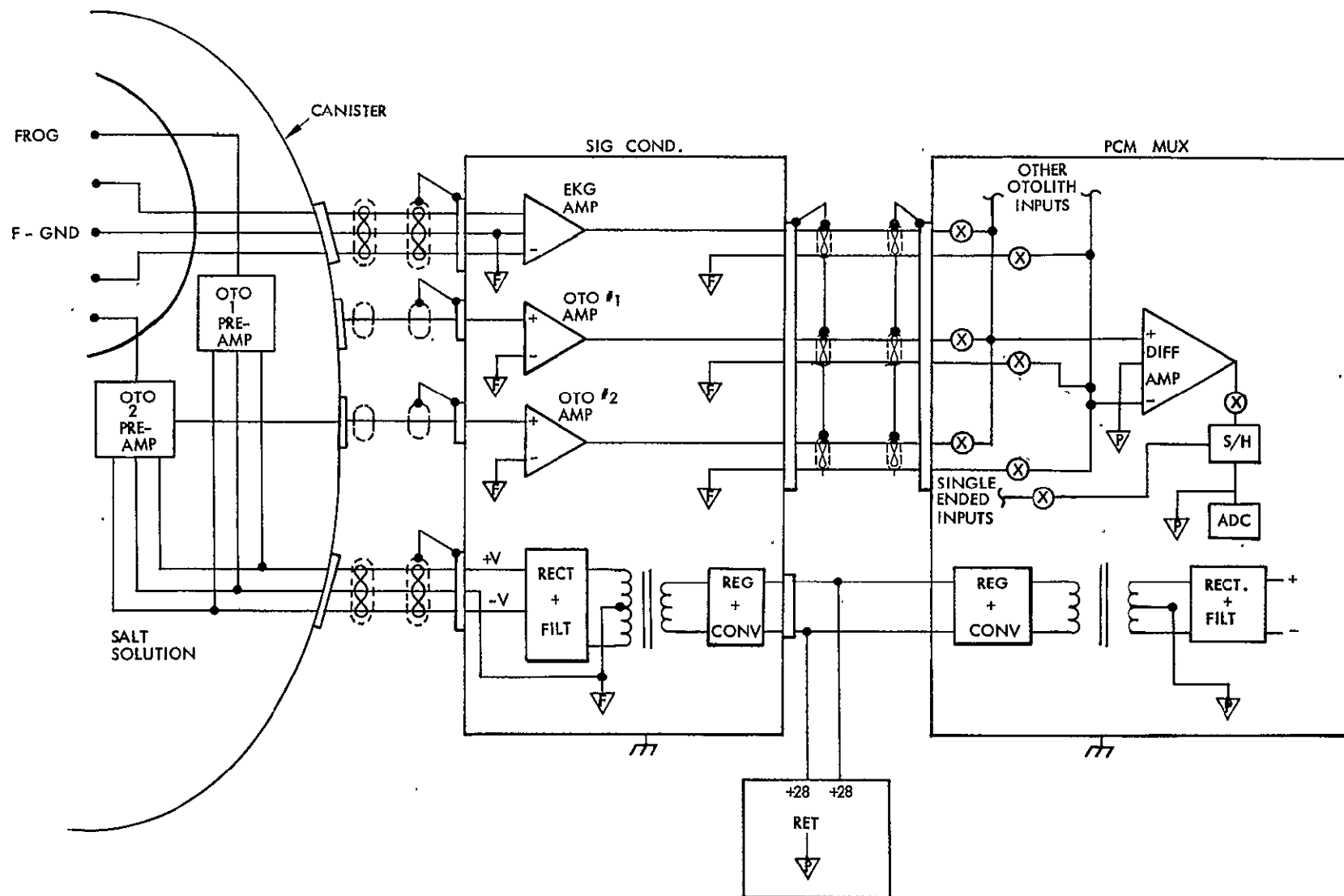


Figure 94 Grounding and Shielding of Bio Data

Instrumentation (Transducers)

The preliminary design of the Data System includes the preliminary selection of transducers necessary to provide the measurements listed in Table 15 and any other special data system functions. Descriptions of the transducers selected for use within the Life Support System are included in the life support section of this report. Descriptions of all other transducers are given in Table 17.

Electrical Power System

The VFR electrical power distribution system functional block diagram is presented by Figure 95. At present, it appears feasible that the VFR experiment can be powered from the Spacelab essential power bus during prelaunch, ascent and orbital operation and therefore, a battery has not been included into the design, but can easily be incorporated as an optional power source. The battery depicted in Figure 96 can supply power to the VFR experiment during prelaunch, ascent and early orbit for a period of $2\frac{1}{2}$ hours. This particular battery is flight qualified as are several others of various capacity, type and style - a large capacity battery can be used if power interruptions greater than $2\frac{1}{2}$ hours are encountered.

Following the power control and distribution flow in the block diagram, power will be supplied to the manual control and status panel located on the front of experiment rack 12. Two circuit breakers will control power, one for the rack equipment and the other for all centrifuge mounted hardware. The centrifuge circuit breaker will be a short trip style in which a signal from the C&W system will result in tripping the breaker thus disabling the centrifuge.

With the rack circuit breaker closed, power will be applied to the rack decoding logic, which is TTL compatible, the transistor relay drivers (open collectors) and relay module. Additional power will be available to the life support module circuit breaker which can now be energized. The relays will be latching type, DPDT, LS41022 (5 amp) and LS41003 (2 amp).

Closing the centrifuge circuit breaker will supply power to the centrifuge mounted power control and distribution unit and to the microcomputer power switch. Energizing the switch will power up the computer and the running of the preprogrammed

Table 17 Transducer Descriptions

<u>Measurement/Sensor</u>	<u>Quantity</u>	<u>Manufacturer</u>	<u>Part No.</u>	<u>Description</u>	
				<u>Vol.</u>	<u>Wt.</u>
+5 g 3 axis frame accelerometer	1	Entran Devices, Inc.	EGA3-1251	.5"x.5"x.5"	10 g
+1 g 3 axis frog head accelerometer	7	Entran Devices, Inc.	Similar to RGA3-1251	.3"x.3"x.3"	6 g
Acoustic Noise Sensor	1	Endevco	2510 AM	1"x1.68"x.94"	2 oz
Charge Amplifier	1	Endevco	2644M107	2.3"x1.5"x1.0"	5 oz
Canister Water Temp (Thermistor)	6	Fenwal	LTN-2	Bead (.110x.16)	<1 g

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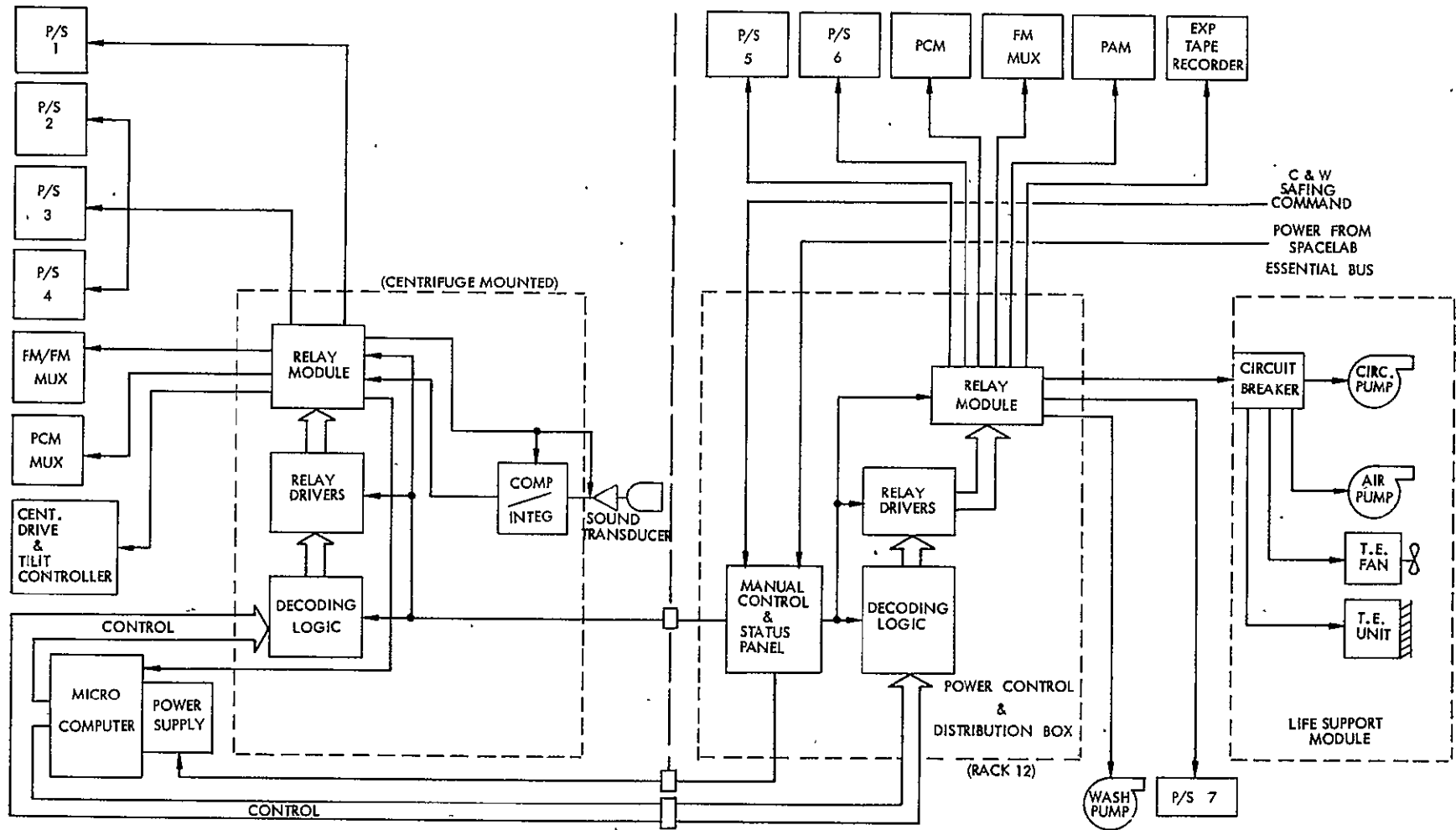


Figure 95 Electrical Power Distribution System

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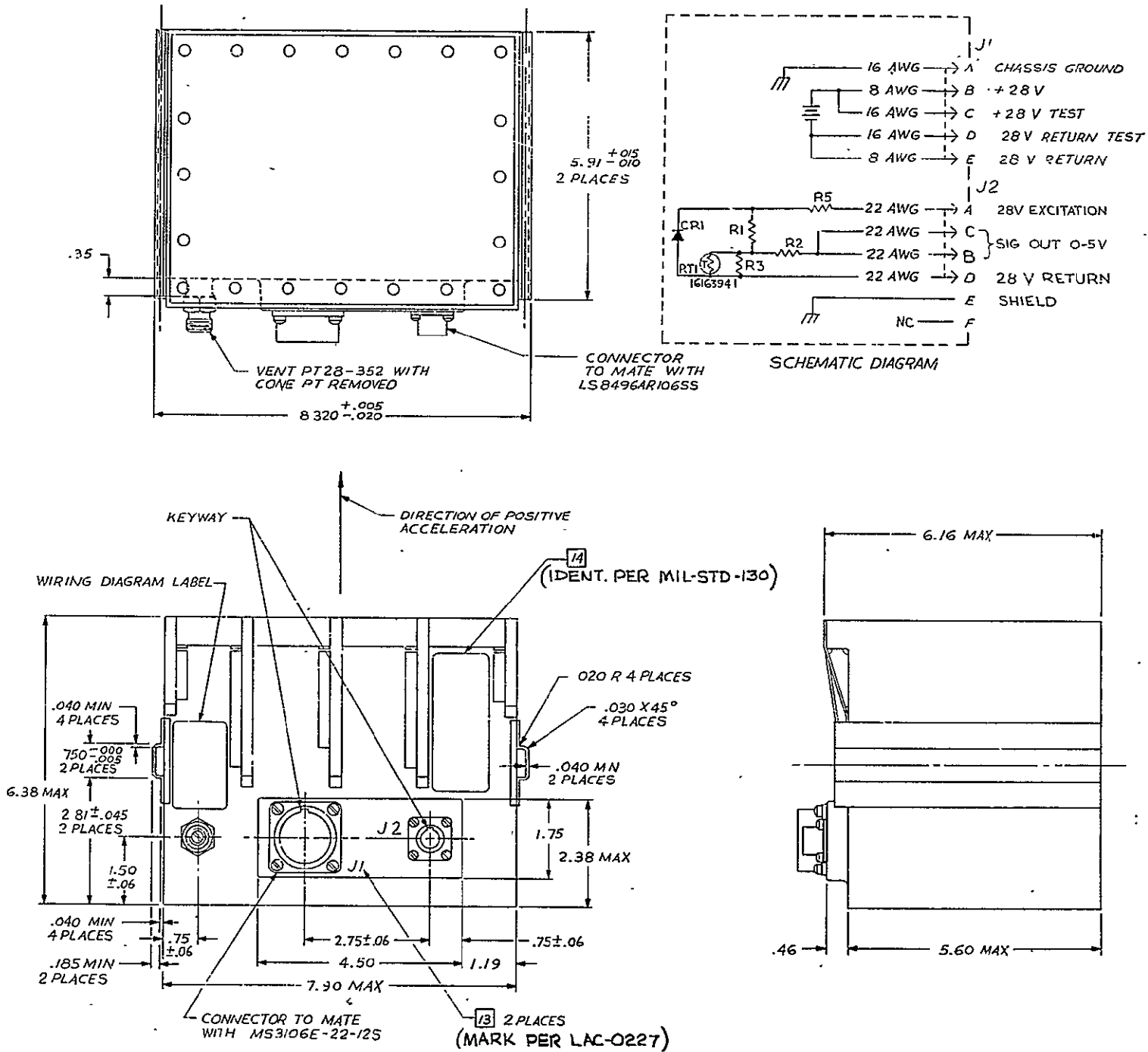


Figure 96 Experiment Battery

instructions will begin. The microcomputer controls power to the following via the rack and centrifuge decoding logic, driver and relays.

- All power supplied (for signal conditioners)
- All multiplexers
- Centrifuge drive and tilt controller
- PCM
- PAM
- Tape recorder
- Wash pump

The TTL compatible decoding logic will receive instruction from the microcomputer by a parallel, six bit, binary word, updated each minute. The logic decodes the word, biasing the base of the appropriate open collector transistor relay driver which in time will energize the appropriate coil of a latching relay.

An acoustic sound transducer will detect the high acoustic sound pressure level during main engine and solid rocket booster ignition. The signal will be amplified and go to a comparator and integrating circuit where if two conditions are met, will result in an interrupt signal to the microcomputer, signaling T=O. The two conditions are 1) sound level at a preset minimum level and 2) the sound level continuously present for a predetermined period of time. The sound detection circuit will be disabled following T=O detection, preventing a possible erroneous signal causing a reset to T=O.

The rack 12 panel will contain two inhibit lighted pushbutton switches enabling flight and ground crew members to interact with the system without associated danger. These are: 1) centrifuge inhibit and recorder inhibit and when depressed will allow access without the equipment being activated by the microcomputer.

Table 18 presents the electrical power summary for the VFR experiment. Peak power is the maximum power that a component may require under maximum local conditions.

Table 18 Electrical Power Summary

	Qty.	Peak Power (W)	Mission Duty Cycle (%)	Mission Avg. Power (W)	Ascent Pwr (W)	Descent Pwr (W)	Total Energy (KWH)
Centrifuge Controller	1*	60	100	60	60	0	11.5
Centrifuge Drive Motor	1	275**	22.8	2.88	0	0	0.53
Canister Tilt Motor	4	10	NIL	—	—	—	—
Micro Computer	1	5	100	5	5	5	0.96
Power Control & Distribution	2	15	100	15	15	10	2.83
Continuous Data Electronics	1	15	96	14.4	15	0	2.76
Periodic Data Electronics	1	75	31	23.3	75	0	4.46
Tape Recorder	1	115	15.1	17.4	115	0	3.2
Thermal Electric Unit Fan	1	10	100	10	10	10	1.92
Thermal Electric Unit	1	15	100	15	15	15	2.88
Thermal Electric Control	1	15	100	15	15	15	2.88
Wash Pump	1	73	2.5	1.8	0	0	0.35
Air Pump	1	10	100	10	10	10	1.92
TOTALS				224.8	395	135	42.9
*Energy Saving Option (Controller Off When Not Used)		60	29	18	0		3.4
TOTALS With Option				165	335	135	34.8

**Peak Power occurs for very short period
10 watts maintains centrifuge speed

The mission duty cycle is the percent of time a component is operated during pre-launch, orbit and re-entry.

Mission average power is the normal running power times the mission duty cycle. Ascent and descent power is the power required during those periods. Total energy is the orbit average power times 192 hours, divided by 1000 to give kilowatt hours.

Approximately 9 kwh can be saved if the centrifuge controller is turned off at all times except when spin cycle or artificial gravity is required. However, by deactivating the controller, the centrifuge and canisters are not locked in place. When power is re-applied the canister will be repositioned to the original position as commanded by the computer memory.

Fig. 97 illustrates the anticipated electrical power profile of the VFR experiment, beginning with specimen loading and continuing until after the space lab is activated. Approximately 290 watts of power are required to run the life support system, operate the computer and record continuous acceleration data. During periodic biological, engineering and housekeeping data recordings, 370 watts of power are required. As spacelab is activated and the acceleration data is downlinked the power requirements drop to 180 watts for life support and essential data and control electronics. Power consumption rises to 260 watts when the periodically operated data system is energized for a data transmission and centrifuge spin cycle.

The reduction by approximately 110 watts at space lab activation, is due to the VFR experiment recorder not operating. The centrifuge torque motor will peak at approximately 275 watts during the start of a spin-cycle, but will extend for a very short period and will level off to approximately 10 to 15 watts during the steady g levels. The dashed line on Fig. 97 presents the power profile for the option of timing off the centrifuge controls when not needed.

233

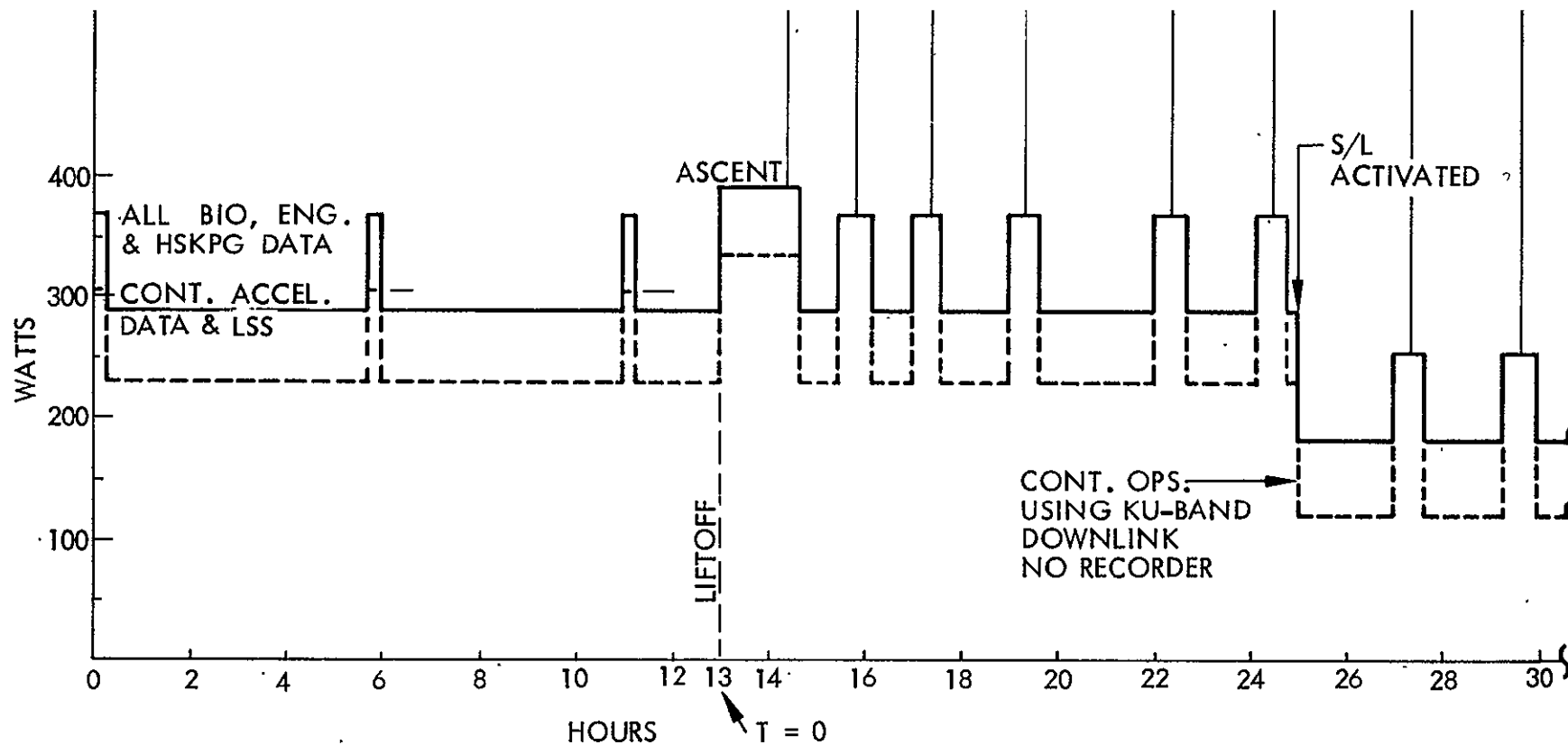


Figure 97 Electrical Power Profile

Rack Mounted Equipment

Equipment not mounted on the centrifuge is located in rack 12 of the Spacelab. Connections to the centrifuge are made by fluid lines and electrical cables which run down the back of the rack and under the floor to the centrifuge.

Rack 12 has some permanently installed equipment which limits the space for installation of VFR experiment equipment. The bottom 70.6 cm contains the remote acquisition unit (RAU) and the experiment power switching panel (EPSP), and therefore is unusable. In addition, the back of the rack contains cooling air ducting and the fire suppression system, which precludes installation of experiment equipment in that area. The remaining space is used to house the VFR experiment life support, electrical, and data equipment.

The VFR rack mounted equipment, shown by Fig. 98, is packaged into three drawer type assemblies. The bottom drawer serves two functions, i.e., life support for the six frogs when in Spacelab and life support on the mid deck during entry. The life support components not required as part of the mid deck transporter and the two control frog canisters are mounted in the middle drawer. The tape recorder is in the top drawer which is also removeable to facilitate servicing and tape changes. The remaining rack mounted data system components are mounted to two frames which are secured to the tape recorder guide rails.

The front panels of the rack are removable to allow quick access to any equipment for maintenance or checkout.

This packaging arrangement assures the structural integrity necessary to meet all environmental loads, while meeting mission requirements and assuring maximum reliability and maintainability.

Life Support Drawer (Mid deck transporter)

Life support requirements on the mid deck include oxygen supply, carbon dioxide removal, temperature control, water

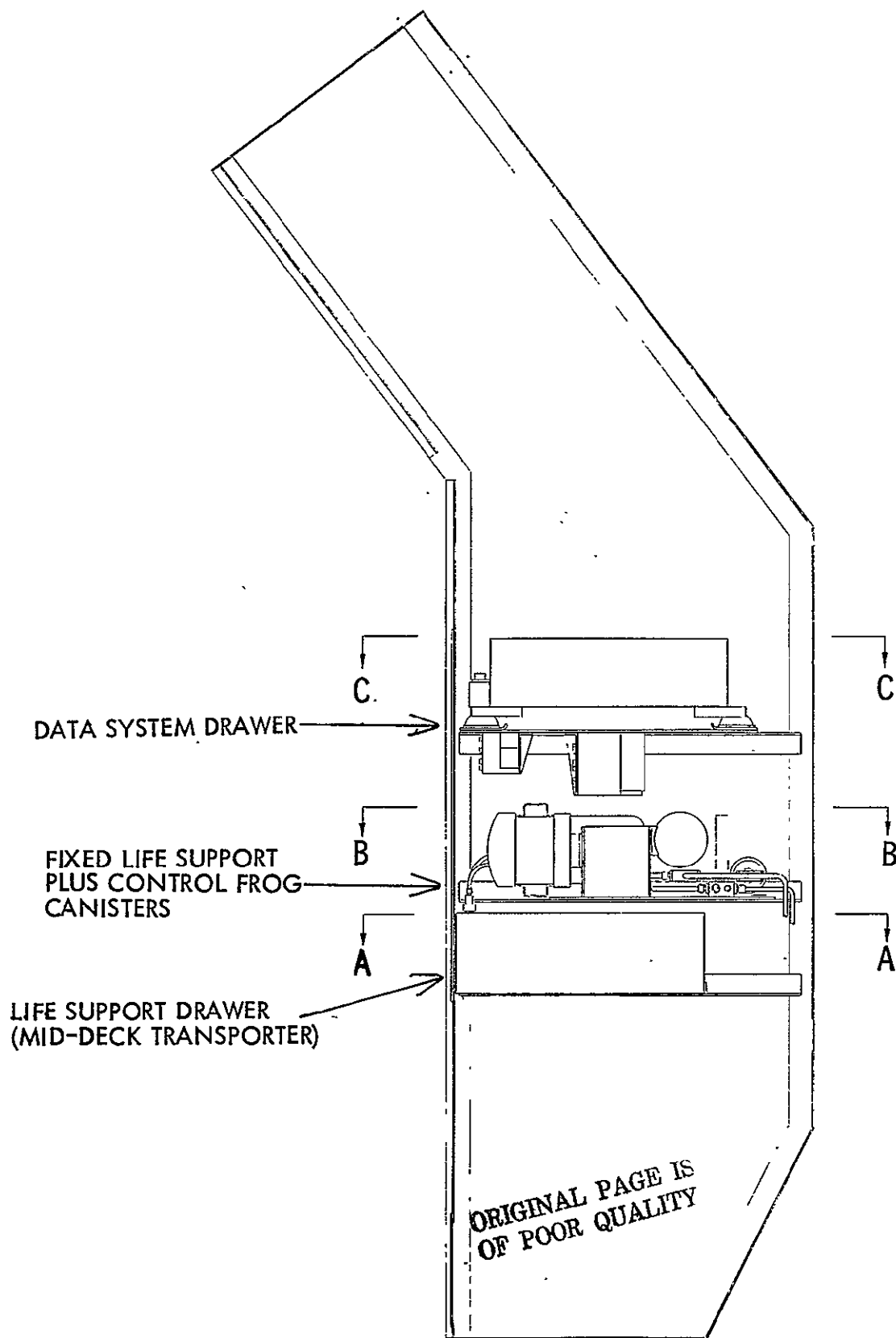


Figure 98 Rack Mounted Experiment Equipment

circulation, solids removal, and urea control. It is also required that the life support equipment fit into the space normally occupied by mid deck lockers.

To meet these requirements the removal life support drawer includes the filter, lung, circulation pump, liquid accumulator, baralyme canister, oxygen bottle and regulator, and the thermoelectric unit with blower and controller.

As shown by Fig. 99, the components are packaged in a structure consisting of a 1 in. x 1 in. x 1/8 in. aluminum angle frames with 0.060 in. sheet metal covers on all sides. The overall size is 17-1/4 in. wide x 20-3/8 in. deep x 6-1/2 in. high. Sides, back, and bottom are permanently attached and the top is removable for access and servicing. The unit is sized to fit in the space of a standard mid deck locker.

Components are bolted directly to the bottom or sides of the structure, as required. Some items such as pressure transducers and plumbing are retained by elastomer lined clamps.

Interconnecting lines and fittings are polyethylene to reduce weight and provide electrical isolation of the fluid. All main liquid lines are 3/8 in. O.D. Polyethylene fittings will be of the Swagelock flareless type, while stainless steel are MS flared type.

All components except the pump motors are insulated with 2 lb/ft³ density polyurethane foam. Approximately 1 in. of insulation is used on most components. All insulation is bonded in place and is coated with an intumescent fire retardant coating. The coating has a water base, is non-flammable and non-toxic, and is easy to apply by brushing or spraying it onto the foam surface. Intumescence begins at approximately 500°F. Phenolic or similar insulating spacers are used between components and the metal structure.

As shown in Table 19 the life support module weighs 52.4 lbs. complete with all water and oxygen. A complete breakdown of all major items is presented. Weights for the other items in the system, located outside the module, are also provided.

~~REDAUT FRAM~~ 1

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BLOWER PRESSURE
TRANSDUCER

LUNG

PRESSURE RELIEF
VALVE

OXYGEN
REGULATOR

ACCUMULATOR

OXYGEN PRESSURE
TRANSDUCER

FILTER AP
TRANSDUCER

FILTER

OUTLET QUICK-
DISCONNECT
COUPLING
INLET QUICK-
DISCONNECT
COUPLING

PUMP PRESSURE
TRANSDUCER

CO₂ REMOVAL
CANISTER

AIR PUMP

OXYGEN TANK

CIRCULATION
PUMP

THERMO-
ELECTRIC
UNIT

PUMP PRESSURE
TRANSDUCER

THERMO-ELECTRIC
UNIT CONTROLLER

SECTION A-A

Figure 99 Life Support Installation
(Mid Deck Transporter)

Table 19
LIFE SUPPORT SYSTEM WEIGHT SUMMARY

LIFE SUPPORT MODULE

Thermoelectric Module	13.1 lbs
TE Fan + Converter	0.4
TE Controller	1.0
Baralyme Canister	3.4
O ₂ bottle (full)	1.6
O ₂ Regulator	0.7
Air Pump	0.6
Lung	1.8
Filter	2.3
Accumulator	2.5
Circulation Pump	3.0
Pressure Transducers	2.7
Relief Valves	0.1
Lines & Fittings	0.7
Mtg. structure	9.3
Insulation	1.3
Fasteners, clamps, wiring	4.4
Fluid	<u>3.5</u>
Total Module Wgt	52.4 lbs

OTHER ITEMS (excludes items on centrifuge)

Water Tank	3.2
Wash Pump	3.3
Ph Sensor	0.8
Pressure Transducer	0.3
Check Valves	0.9
Relief Valve	0.2
Lines & Fittings	5.2
Mtg. structure	17.3
Insulation	3.7
Fasteners, clamps, wiring	4.4
Fluid	12.3
Control Connectors	<u>41.5</u>
	93.1 lbs

TOTAL SYSTEM WEIGHT 145.5 lbs

The unit is mounted on two large rails which are attached to the inside of the rack structure. Bayonet pins are provided on the back, and quarter turn fasteners are provided on the front. Quick disconnects and an electrical connector are provided at the front of the module to allow easy removal.

Removal from, or return to the rack is accomplished by loosening or tightening the front fasteners, removing or connecting the quick disconnects and electrical connector, and sliding the unit out of the rack. Handles are provided on the top of the unit to assist in lifting it.

Middle Drawer (fixed Life Support and Control Frogs)

Life support items mounted outside the lower drawer include the wash pump, water tank, check valves, and the two control cannisters. These items are mounted in a Spacelab rack, as shown by Fig. 100. The basic package size is 19 in. wide x 26 in. deep x 8-1/2 in. high.

The mounting structure consists of a base, which has sheet metal mounting brackets welded to it, and mounting rails which adapt the unit to the rack structure. A clamp ring assembly is provided to mount the canisters to the structure. They have over center latches to allow quick canister removal.

All items attach to the structure of the base, or are mounted with clamps. As in the lower module, plastic lines and fittings are used when possible. Internal fluid lines, are 3/8 in. OD. Cannister lines are 1/4 in. OD. All items are insulated with polyurethane foam coated with an intumescent coating.

Manifolds are provided at essential points to allow connection of fluid lines and sensors with the minimum possible plumbing. Manifolds are used at the outlet of the wash pump, for the check valves, and for the pH sensor and relief valve. Quick disconnects are provided for the cannister fluid lines and for passage of the fluid to the life support module. The mating half of the life support module electrical connector is also located

REWORK FRAME 2

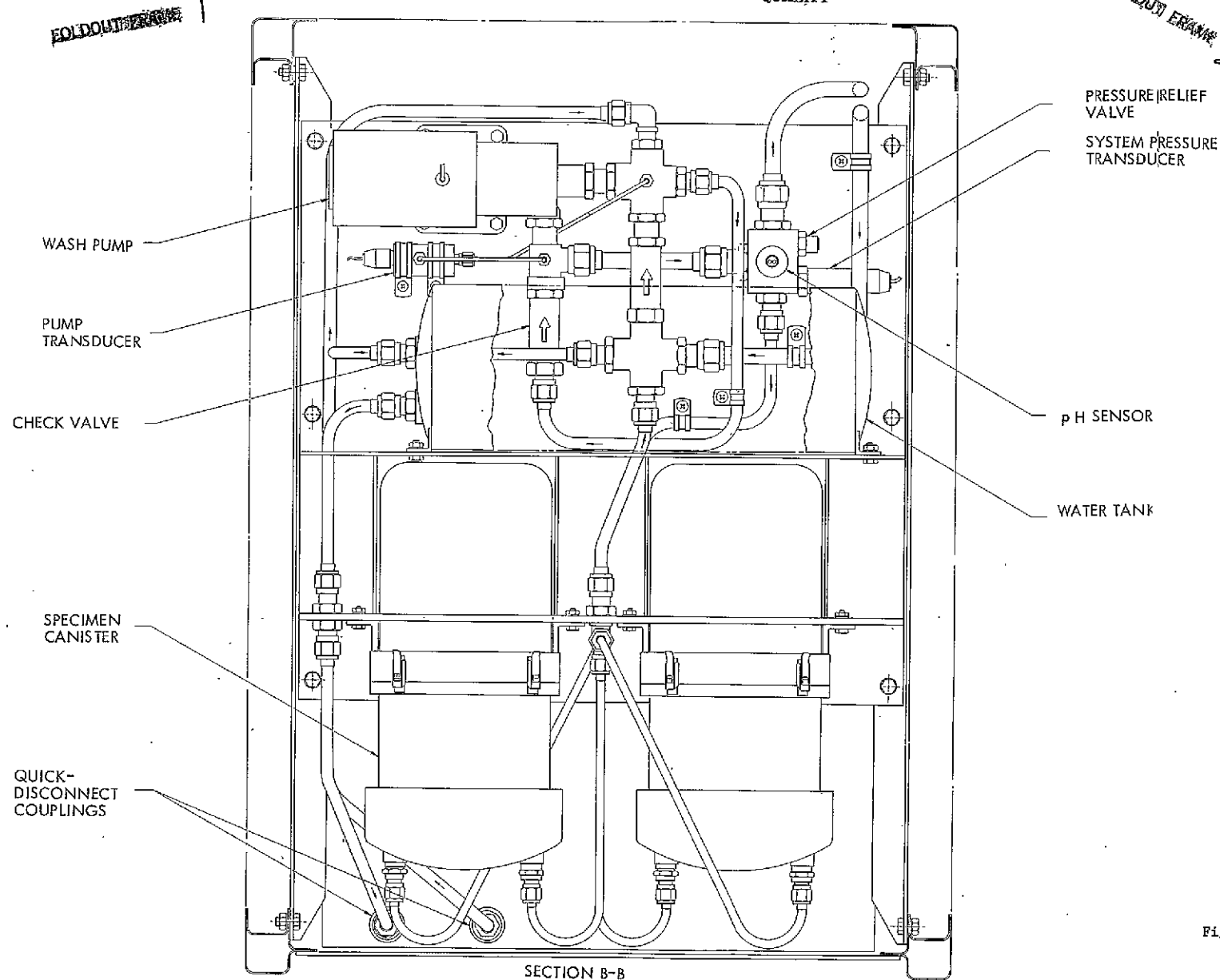


Figure 100 Fixed Life Support and
Control Frog Canister
Installation
240

in this unit.

Water and electrical connectors to the centrifuge run down the back of the rack and under the floor. One-half inch O.D. polyethylene lines are used to reduce pressure drop. As there is little temperature difference between the lines but a large temperature difference between the lines and the cabin, one line is insulated with about 1/4 in. of insulation to separate it from the other line and the two lines are wrapped in a polyurethane foam insulating sleeve about 2 in. in outside diameter. It is externally coated with the intumescent coating.

Data System Drawer

Tape recorder mounting requirements include removal for servicing, and isolation of the unit from environmental loads, especially sine and vibration.

To meet these objectives the recorder is mounted to four elastomeric shock mounts which, in turn are mounted to a metal frame assembly. Mounting rails are provided to attach the unit to the Spacelab rack.

As shown in Fig. 101, the frame is fabricated from 1/8 in. aluminum sheet. It has bolts at the front and back which attach it to the mounting rails. The front bolts are directly accessible and the rear bolts have actuating rods attached which allow access from the front of the unit. The mounting rails are 2 in. x 1-1/2 in. x 1/2 in. extruded aluminum angles. They have guide brackets riveted to them which guide the recorder as it is pushed in or out of the rack. Nut plates are attached at the front and back to receive the frame attachment bolts. The rails are bolted directly to the inside of the Spacelab rack. Data equipment mounted to the bottom of the tape recorder support rails includes the control data PCM multiplexer/encoder, the PAM submultiplexer, the life support system signal conditioner, the control VCO assembly, the PCM selector switch, and three power supplies. The power supplies are used for the signal conditioner on the rack mounted cannisters, and the life support system signal conditioner. All items are bolted directly to two aluminum brackets which are bolted to the bottom of the tape recorder mounting rails.

EOLDOUT FRAME

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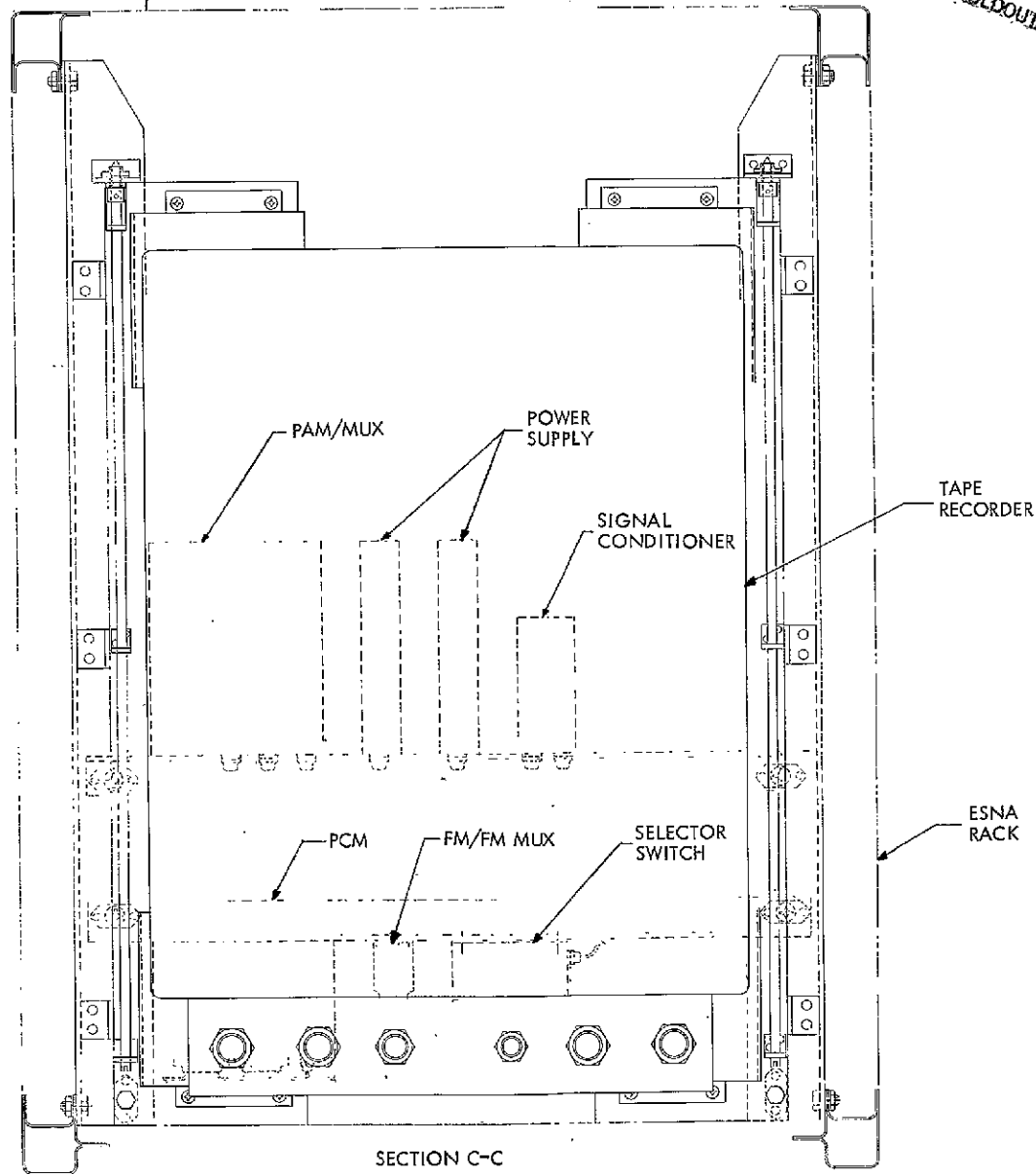


Figure 101 Data System Installation

Mid Deck Installation

The mid-deck mounting structure is used to store the six flight specimens during preparations for and during reentry. This allow swift recovery after landing, as the Spacelab cannot be entered immediately. The Spacelab life support system is designed to support six frogs in both locations. This is accomplished by removing a major portion of the life support system from the Spacelab rack, and installing it in the mid-deck location. Life support components required on the mid-deck have been packaged into a portable mid-deck transporter module. Figure 102 presents a layout of the mid-deck VFR equipment installation.

The mid-deck structure consists of a metal mounting frame which replaces three standard mid-deck lockers. It holds six frogs in their canisters, has a mounting space for the life support module, and has all the necessary plumbing to allow connection of the life support module to the canisters. Also, it has the required wiring for power supply to the life support module. There are no other direct vehicle interfaces other than a power supply connection. The life support module rejects heat directly to the cabin air through the thermoelectric unit. The mounting frame consists of a welded and riveted sheet metal assembly. Overall size is 21-1/2 in. deep x 18 1/8 in. wide x 32-3/4 in. high. The unit has sides, a back, and internal mounting structure.

The sides of the unit are triangularly shaped and are constructed of 1/8 in. sheet aluminum. They are 9 in. across at the top, 21-1/2 in. at the bottom, and extend over the full height of the frame.

The bottom of the sides are bent over to serve as mounting rails for the life support module. It slides in and out on them, and attaches to them at the front with quarter turn fasteners. There are brackets riveted to the sides, at the rear, which intercept guide pins at the rear of the module.

The back of the unit consists of two 1 x 1 x 1/8 angles which run vertically over the

ROBOUT FRAME

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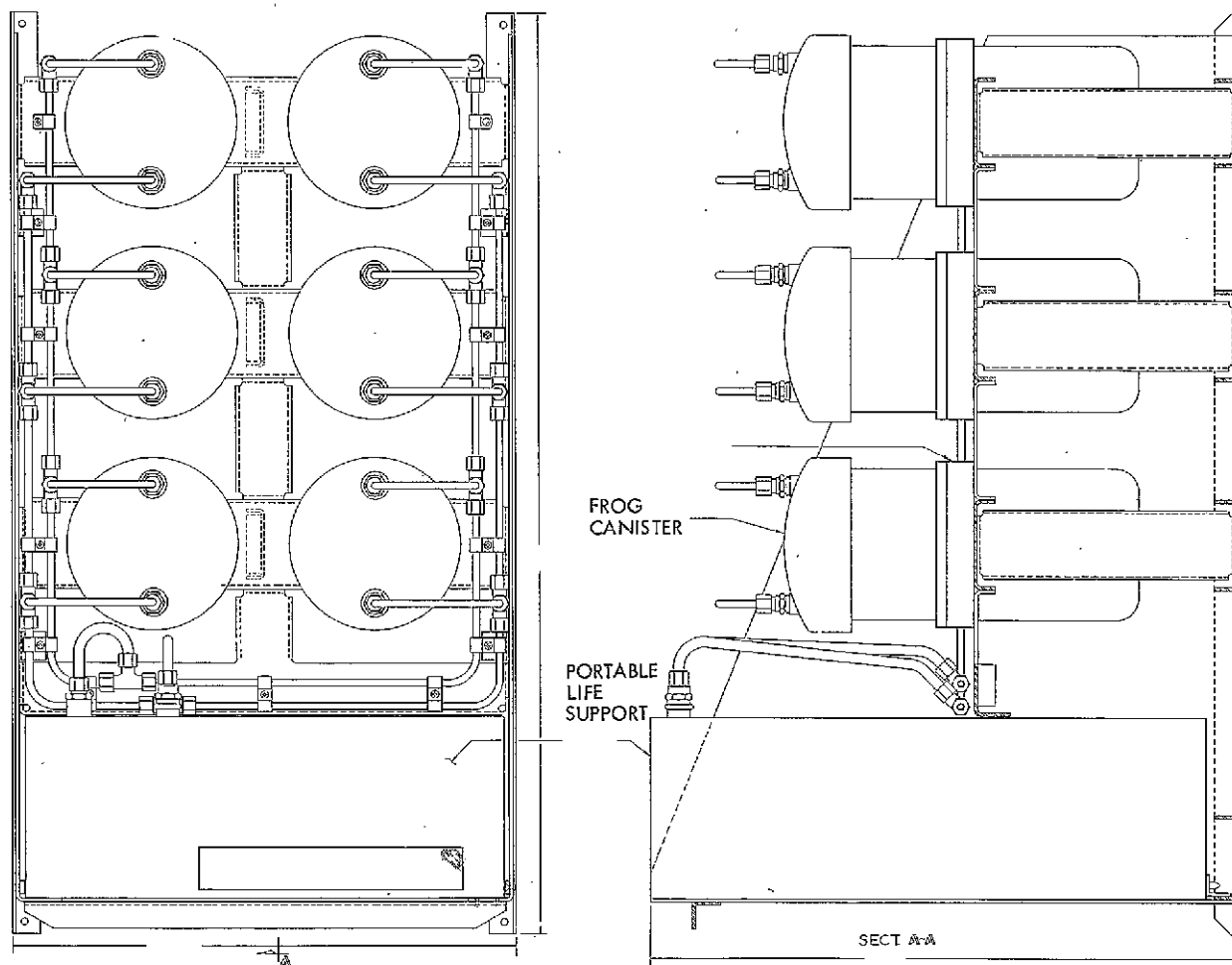


Figure 102 Mid Deck Installation

full height of the unit and serve to mount it to the mid-deck structure, and three 3 in. x 3/4 in. x 1/8 in. thick fabricated aluminum channels which run across the back of the unit. Bolts are used to secure the angles to the mid-deck locker attach points.

The internal mounting structure consists of sheet metal brackets which support the frog canisters. Three 3 in. x 3/4 in. x 1/8 in. channels run across the center of the unit, between the sides. Mounting rings, which allow quick removal of the canisters by unsnapping two over center latches, are welded to the channels. Three other brackets attach to the back channels and front channels to provide horizontal stiffness.

Plumbing and wiring is attached directly to the sides and front cross channels by elastomer lined clamps. Plumbing and fittings are polyethylene where possible. Quick disconnects are provided to mate with those on the canisters.

VFR Experiment Weight Summary

The VFR flight experiment hardware weight summary is presented by Table 20. The total weight of the entire experiment is 676 lbs. (307 kg). This is split between the rack equipment at 277 lbs (126 Kg) and the centrifuge at 399 lbs (181 Kg) including the centrifuge structural support which is 95 lbs (43 Kg). Leaving a rotating mass of 303 lbs (137 Kg). The rack life support module weight is 52 lbs (24 Kg) which is easily disconnectable and will be transported to the mid-deck immediately prior to Spacelab deactivation.

Table 20.

WEIGHT SUMMARY - RACK MOUNTED EQUIPMENT

DATA EQUIPMENT:		<u>lbs</u>
Signal Conditioner	(1)	1.0
Power Supply	(1)	1.0
FM/FM Mux	(1)	2.2
PAM Submux	(1)	1.3
PCM MUX	(1)	8.0
Tape Recorder	(1)	65.0
Select Switch	(1)	0.25
Misc Transducers		1.0

Table 20 WEIGHT SUMMARY - RACK MOUNTED EQUIPMENT (continued)

Cable harness	30.0	
Mounting, Brackets, Fasteners	10.0	
		118
Power Control and Status Module	11.0	
ables, Fasteners	3.2	
		14
LIFE SUPPORT MODULE:		
Thermoelectric module	13.1	
T.E. Fan and Converter	0.4	
T.E. Controller	1.0	
Baralune Canister	3.4	
O2 tank (full)	1.6	
O2 Regulator	0.7	
Air Pump	0.6	
Lung	1.8	
Filter	2.3	
Accumulator	2.5	
Circulation Pump	3.0	
Pressure Transducer	2.7	
Relief Valve	0.1	
Lines and Fittings	0.7	
Mounting Structure	9.3	
Insulation	1.3	
Fasteners Clamps, Wiring	4.4	
Fluid	3.5	
		52
NON-MODULE LIFE SUPPORT ITEMS:		
Water Tank	3.2	
Wash Pump	3.3	
Ph Sensor	0.8	
Pressure Transducer	0.3	
Check Valves	0.9	
Relief Valve	0.2	
Lines and Fittings	5.2	
Mounting Structure	17.3	
Insulation	3.7	
Fasteners, Clamps, Wiring	4.4	
Fluid	12.3	
Canisters (2)	40.6	
		93
TOTAL RACK EQUIPMENT		277

Table 20 WEIGHT SUMMARY - CENTRIFUGE (continued)

ROTATING

DATA EQUIPMENT

lbs

Signal conditioners	(8)	8.0	
Power Supplies	(4)	4.0	
PCM MUX	(1)	8.0	
VCO Assy.	(1)	0.2	
Wiring harness		8.0	
Fasteners, brackets		1.9	
			30
Power Control and Distribution		5.0	
Cables, Connectors, Fasteners		4.2	
			9
Canister Assy:			
Canisters (4 @ 20.3)		81.2	
Tilt Motors (4 @ 3.5)		14.0	
Gimble Assemblers (4 @ 12.8)		51.2	
Balance weights		1.9	
			148
Hub & Arm Structure		65.8	
Motor & brush block		50.0	
			116
			303
NON ROTATING			
Support Structure		67.9	
Motor, Fluid joint, sliprings		27.5	
			95
		Total Centrifuge	399
		TOTAL VFR EQUIPMENT WT. =	676 lb.
			(307 Kg)

Mission Operations

An essential part of the preliminary design of the VFR experiment was the integration of the experiment into the Spacelab/Shuttle mission operations. To better define the experiment hardware, vehicle interfaces, ground support requirements and experiment operations the following data was generated.

- Experiment mission timelines were established
- Experiment ground support equipment were defined
- An experiment operations plan was prepared
- VFR experiment personnel requirements were established
- STS on-board equipment requirements were defined

Experiment/Spacelab/Shuttle Timelines

The following paragraph describes the anticipated timelines for prelaunch, orbit and post landing of S/L III, relative to the VFR experiment and its impact on orbit in operations. They were derived from launch assessments jointly, prepared by the KCS Orbiter Processing Branch (VT - VPD - 1) and KSC Payload Processing Branch (VT-VPD - 2). As experience is gained for ground operations on future orbiter and space-lab flights, access and experiment ground operations may change in length and/or point of access.

Prelaunch

Fig. 103 presents the significant activities and time spans associated with orbiter operations on the PAD. The orbiter arrives at the pad on the Mobile Launch Platform (MLP) at T-26 hours in the vertical position.

During the first few hours, two major activities are underway. One is the Orbiter operation involving MLP mating, Service preparations and launch readiness verification testing. The other concerns experiment hardware operations and only the VFR hardware will be discussed herein, realizing that Payload Changeout Room (PCR) activities for S/L III may involve other experiments.

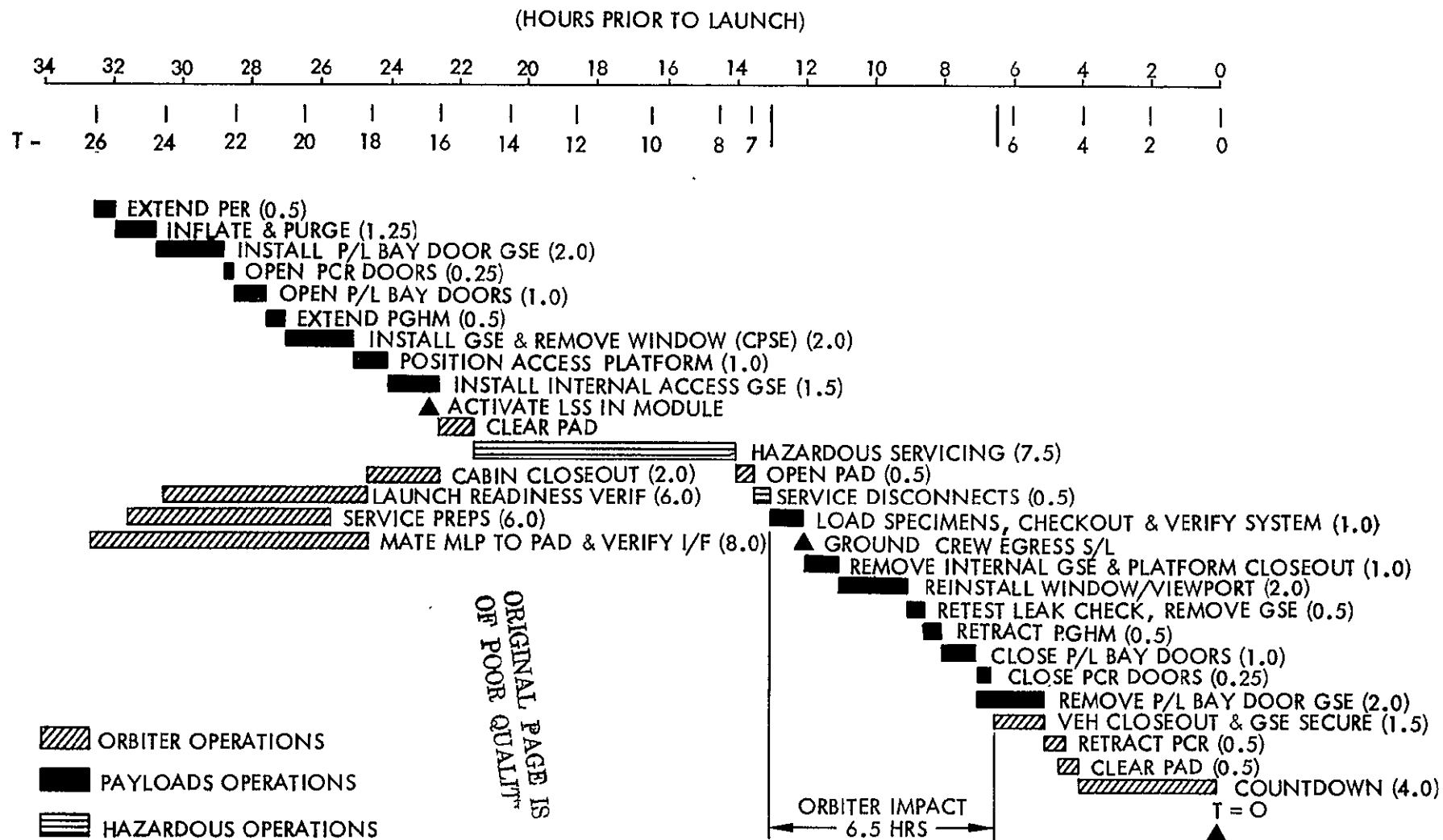


Figure 103 Prelaunch Operations

At approximately T-16, the VFR life support system will be activated in order to prepare the system for specimen insertion later in the countdown. Hazardous servicing is followed by pad opening and service disconnects and then the frog canisters are loaded into the Spacelab mobile using the vertical access GSE.

It is presently anticipated that specimen loading and system operation verification will require approximately one (1) hour to accomplish. After the specimen have been loaded removal of the access GSE and closeout of the Spacelab Module and Payload Bay will require five and one half hours, therefore, the total impact of specimen loading is about six and one half hours. This time span is a hold to the T time and according to clock time, so the specimen will actually be loaded approximately twelve and one half (12.5) hours prior to launch.

Ascent and Orbit

Fig. 104 present the ascent, orbit operations. Biological engineering and housekeeping data will be recorded during ascent and will continue through orbit insertion and the first spin cycle which occurs within thirty (30) minutes after achieving orbit. The micro computer will control spin cycles and data recording in accordance with a pre-selected program. T = O activation of the program is achieved by use of a launch noise sensing switch.

At approximately T + 12 hours, or perhaps sooner, if it can be achieved sooner, the spacelab will be activated and data and program updating can be accomplished by the command and data link.

Pre-Re entry

Fig. 105 presents the pre-re entry operations. The spacelab will be deactivated at approximately TD-6 hours as shown in Fig. 105. Prior to deactivation the last centrifugation will occur, followed by specimen and life support system transfer to the orbiter mid deck. The orbiter will be thermally conditioned in preparation for re entry during last six (6) hours of the orbital mission.

.251

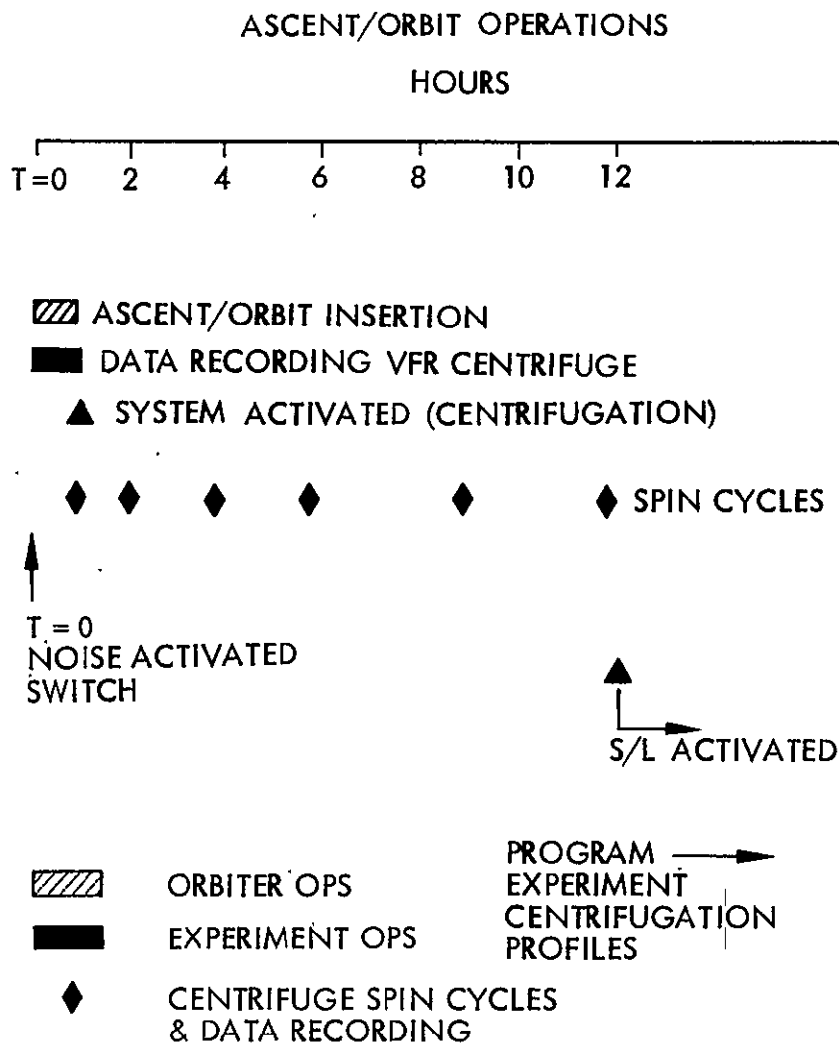


Figure 104 On Orbit Operations

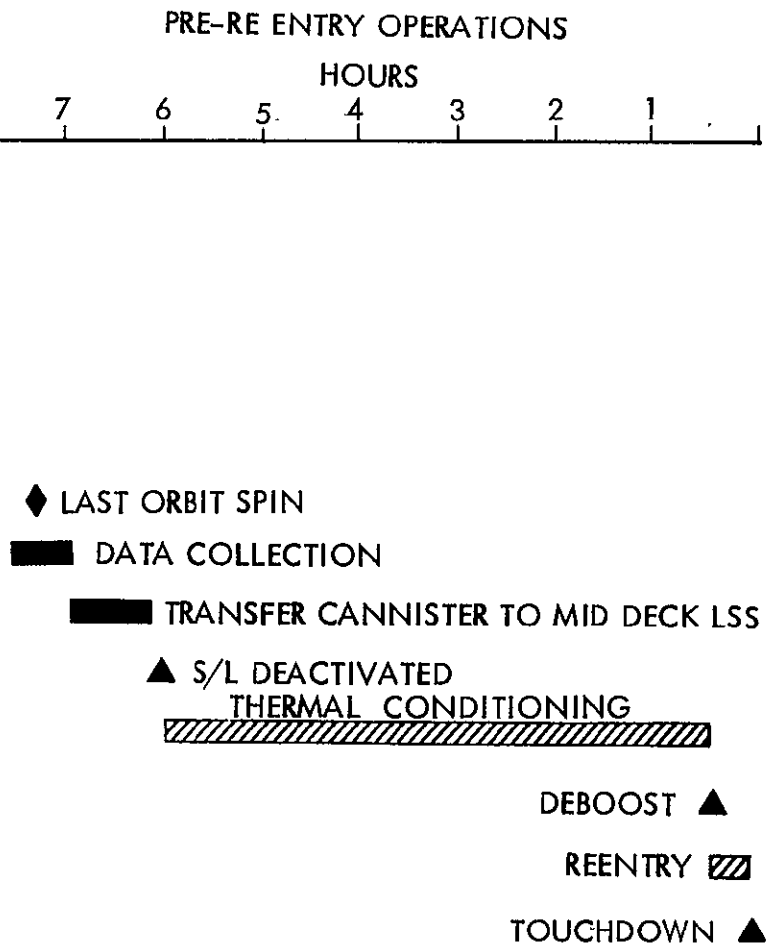


Figure 105 Pre-reentry Operations

Post Landing

Fig. 106 presents the post landing timeline beginning with touchdown of the orbiter. The flight crew will begin egressing the access hatch at approximately TD + 43 minutes. The ground crew could enter the mid deck during this period and without interfering with other activities begin removal of the canisters. Present information and profiles indicate that the orbiter timelines will be impacted by from six to ten minutes for specimen retrieval and will not require additional orbiter GSE to support specimen removal.

Ground Support Equipment Requirements

Ground support equipment (GSE) is required to support the VFR experiment hardware during specimen transport, checkout, testing, servicing and data retrieval and display. The GSE will consist of unique equipment required to support the centrifuge, data system and life support system during various ground operations.

Ten Frog Ground Support Module

This set of GSE will provide life support for up to ten (10) frogs installed in canisters and provide data acquisition, recording, reduction and display for the specimens. additionally data reduction, recording and display of the biological engineering and house-keeping parameters for the flight and qualification units may be performed by this GSE utilizing the demuxing, decoding, digital to analog converters and display devices contained within this GSE.

The ten frog ground support module consists of three sections, i. e. , life support, data reduction, and magnetic tape.

Life Support Section — In addition to providing life support for the ten frogs this section also provides physical support of the frog canisters, data selection switching, and data acquisition and transmission.

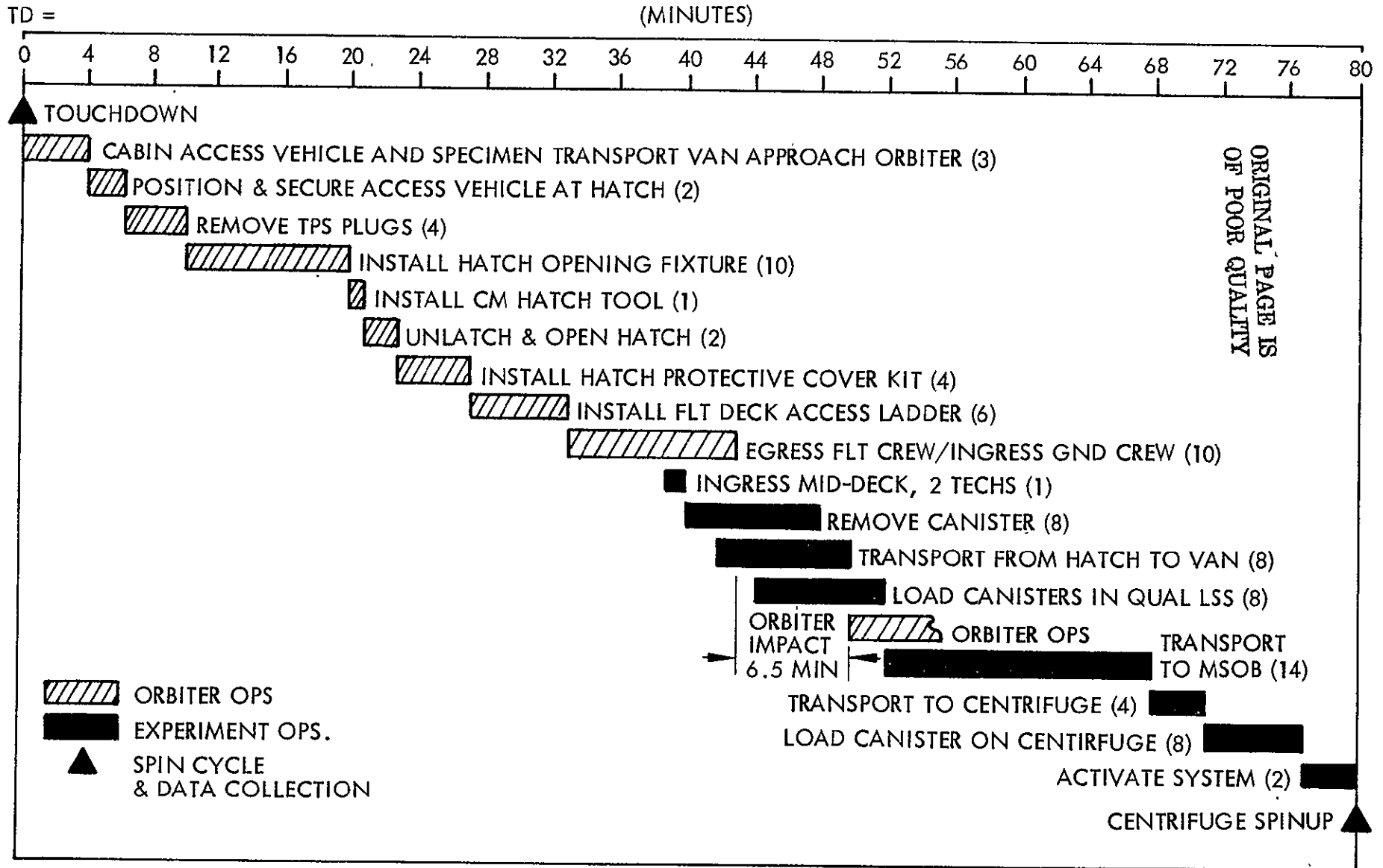


Figure 106 Postlanding Operations

The life support system is mostly made from non-flight hardware and will provide water circulation (Ringers solution), temperature control by a conventional liquid air conditioner, maintain O_2 concentration and remove CO_2 via a flight type lung and control liquid and solid waste by filtration and water bleed. The basic design, flow and functions will be like that of the flight system. Housekeeping data such as temperatures, delta pressures, flow velocities, warnings, etc., will be displayed on gages and dials and will not require a digital interface to the data system.

The support mechanism will provide mounting and retention capability for up to 10 frog specimens canisters including electrical and liquid line supports. It will be designed in two sections, one for six (6) frogs and the other for four (4) frogs. The six frog canister rack will be easily removable and utilized to contain the flight canisters during transit from the MSOB to the spacelab as part of the KSC transport unit.

The data selection switching equipment provides for switching between the groups of canisters for biological and engineering data. The selection will be in groups of 4, 4 and 2 canisters or dictated by the data system multiplying scheme. Some flight type data processing equipment can be used in the ground cart to avoid the expense of designing special ten frog data processing equipment.

The data portions of the life support section will provide conditioned and regulated power to the sensors implanted in the specimens and to sensors in and on the canisters. It also provides the necessary PCM MUX, FM/FM MUX, power distribution and control capability for data acquisition and transmission.

A control panel of the life support section provides the man-machine interface for manual control and/or override for the life support system. The controls (with appropriate displays) will be arranged in a flow and functional schematic on the panels for ease of understanding and operation. Additionally it will provide the interface point for the qual tape recorder during the transport from the PI's lab to MSOB and the post-flight return.

Data Reduction Section — This section provides for data decoding, digital to analog conversion, data control and display and power supply. The decode portion provides the capability to demultiplex incoming data directly from the flight or qual unit, the GSE mounted canister or from the GSE recorder. It also provides bit synchronization and decommutation for data reduction.

The DAC provides the capability to convert digital data to analog of all data channels for subsequent display.

The data control and display equipment provides GSE system control for all data handling, reduction and display. It includes meters, multichannel oscillograph, 8 channel memoscope, oscilloscope and digital displays.

The power supply provides 28 Vdc power to all equipment of the GSE as required. Its input will be from a 115 V, 60 hertz source and will provide adequate warning and protection circuits.

Magnetic Tape Section — This section is assembled with three (3) primary units all supporting data recording, monitoring and play back. Tapes recorded on the flight and qual unit can be played back on this system.

The tape transport unit provides the magnetic tape transport capability of the 1 in. tape and required heads, speed control etc.

The recording electronics equipment provides the necessary electronics for recording the incoming data and monitoring speed, levels and gains.

Playback electronics provide for playback of the data as it is being recorded or of previously recorded data. It too, will provide monitoring capability for gains, levels. etc.

KSC Transport Unit

The KSC transport unit supports six frog specimens in canisters for up to approximately twelve (12) hours or longer, depending on battery capacity. It is used to transport the flight specimens in canisters from the MSOB to the Spacelab module during prelaunch operations. As described in the following paragraph, some components are used from the 10 frog GSE in order to better utilized resources and reduce total program cost. The following segments and units will be contained on a mobile transport cart for easy handling and to minimize perturbation to the specimen.

Qual Unit Segment — The modularized life support system and tape recorder of the Qualification unit is used to support the specimens and record continuous acceleration data during the specimen transport and loading activities. Periodic biological, engineering and housekeeping data may also be recorded, operating the recorder in the high/data rate mode.

Canister Support Segment — The six canister support segment of the ten frog GSE is removed and positioned on the transport cart to securely restrain the canister, cables and fluid lines during transport.

Data Module — This module provides the required PCM multiplexer, FM/FM multiplexer, data select switch, for data retrieval in frog groups of 4 and 2, power supplies, power distribution and status displays. Additionally control functions will be issued from this module to the life support, data and recording subsystems.

Battery — A battery provides power to all system equipment for up to twelve (12) hours. This should be more than adequate for the present planning, but can easily be adjusted up or down to accomodate different mission ground handling requirements. Battery requirements can be reduced by use of a power takeoff from the transport van, if battery life became a problem.

Fill and Bleed Cart

The fill and bleed cart will provide the capability to fill the GSE and flight type LSS with ringers solution and assist in the purging operation of the liquid loop. Sampling points will be provided as well as gages, pumps and necessary controls. Flushing of the system can also be accomplished to clean the system followed a gas purge to dry out the lines and components prior to equipment reuse or storage.

Resupply Cart

This cart will provide storage of consumables such as H₂O (ringers solution), O₂ for recharging the LSS and gases for system purging. The required connections, monitoring devices and controls are included.

Frog Simulator

An electronic module will provide electrical signals which will simulate the implanted frog sensors. The simulator will aid in system checkout, testing both during LMSC operation and integration at the NASA centers.

Van

A van will provide transportation of the VFR experiment hardware and specimens between the aircraft and the MSOB and between the MSOB and the orbiter vehicle, both pre and post orbit. It will provide conditioned air for the equipment to properly function during KSC ground operation involving transporting.

Power Generator

A propane fueled electric generating set will provide electrical power to the GSE during periods that facility or aircraft power is not available.

Automated Checkout Console

An automated checkout console to interfere between the VFR flight equipment and the ATE at KSC will aid in the rapid subsystem checkout during Levels III and II integration.

Operation Plan

The present concept for support of the VFR experiment operation is discussed in the following paragraphs, highlighting activities and describing certain areas that impact orbiter operations, or affect hardware design and support equipment. A qualification unit will be provided that is identical in design, material and process techniques as that of the flight unit. After completion of formal qualification testing it will be refurbished and shipped to the PI's laboratory for use in testing and specimen evaluation. This should occur approximately six months before the scheduled S/L III launch and will offer a period of time to allow testing of specimen characteristics, and through familiarization with the centrifuge, data acquisition and display techniques.

A 10 frog GSE unit will be fabricated using non-flight and in many cases flight type components as described previously. It will be delivered to the experimentors laboratory at the same time as the qualification unit, and can provide support to specimens installed in the canisters. Additionally data playback, reduction and real time display is accomplished via this GSE for the qualification unit specimens as well as specimens on the GSE systems.

The flight and spare units will be shipped to ARC following acceptance test and reviews, and subsequently forwarded to MSFC and KSC for integration into Spacelab III. The flight unit will be installed in the S/L pressurized module at KSC during level III integration activity with interface testing and verification during Level II and I.

Approximately five days prior to launch, the six flight specimens plus four spares will be shipped from the PI's laboratory to KSC by aircraft. The 10 frog GSE will provide life support during transit while the qualification unit recorder will be used to record

continuous 5g acceleration data. The GSE recorder will not be used because it operates from 115v 60 hertz power. Biological, engineering, and housekeeping data may be recorded periodically. During periods that the GSE is not powered by the aircraft electrical system, power will be provided by a ground based auxillary power source (propane power electric generating set). The qualification unit will be deactivated during the specimen transport time span.

Upon arrival at KCS the specimen and equipment will be received and set up in the MSOB. The qualification unit will be activated and can support final specimen testing and verification. The GSE data reduction and tape section may be used to monitor data displays in real time and/or recorded on either the qualification recorder or GSE recorder. The GSE supports all specimens when they are not on the centrifuge system. Continuous acceleration data is recorded for the frog groups or individually when handled one at a time during mounting and demounting.

During the final hours prior to launch the KSC transport unit is prepared to transport the specimens leaving the GSE transporter in a configuration that will support the remaining four (4) specimens in the MSOB. The transport unit will be loaded onboard an air conditioned van for the trip to the PAD with continuous acceleration data recording of one frog's triaxial accelerometer and the frame mounted triaxial 5g accelerometer.

The van will approach the PCR and be positioned as close as practical to the elevator entrance. The transport unit will be off loaded and carried by elevator to the required PGHM access platform for Spacelab loading. It will be placed near the CPSE opening and readied for specimen transfer to the interior of the module. The loading is expected to begin at approximately T-6.5 hours and require no more than one hour. The orbiter will be placed in a hold mode during payload operation.

The first frog canister fluid and electrical connections will be demated and electrical connection remated to a data cassette cable. The canister will then be demounted and handed to the ground crew member inside the module at the CPSE opening. After

receiving the canister, he will lower it carefully down to the crew member positioned at the centrifuge and he will mount the canister to the gimbal. The cassette connector will be demated. The canister will be connected to the flight fluid and electrical hook-ups. (The flight LSS will be activated at approximately T-16 hrs. in order to attain H_2O temperature stabilization by specimen loading time). The cassette will then be removed and the remaining five (5) specimens loaded in the same fashion except the last two canisters will be loaded into rack 12. The microcomputer will be initialized at the beginning of the specimen loading sequence, to allow continuous acceleration data recording with preprogrammed periodic biological, engineering and housekeeping data recording.

An alternate to using the cassette data recorder, associated battery and electronics package would be the use of an extension cable (approximately 25 ft in length) connecting the canister to the transport cart. This would allow continuous acceleration data of each frog's triaxial accelerometer by the transport tape recorder and eliminate two cable disconnections. Additionally the bulk and weight of the recorder package is eliminated during the hand carrying of the specimens, especially during difficult maneuvers associated with the CPSE opening, ladder descent and centrifuge/rack mounting. Easier tracking of acceleration data by frog identity is accomplished by use of extension cables and single recorder rather than using one or two cassettes and switching between canisters.

The program in the microcomputer will activate the applicable portion of the data system periodically to record all data until launch (T=0) an audio sound transducer will sense engine firing. The circuit will integrate and compare the sensed level for a prescribed period (i.e. 1 second) and then initiate an interrupt signal to the microcomputer which in turn interprets it as T=0 and commands the entire data system "on" to record all data. This mode will continue through ascent and orbit insertion. Within 30 minutes after orbit insertion the first centrifuge spin up will occur as controlled by the preprogram instructions in the computer. Data will continue to be recorded until 15 minutes after this centrifugation and then the recorder will be switched to the low speed mode to continuously record acceleration data from one frog's triaxial

accelerometer. Periodic centrifuge spin up cycles together with data recording will be commanded by the microcomputer until the spacelab is activated -- at approximately T + 12 hours. After spacelab activation, time in the VFR microcomputer can be updated and reprogramming accomplished via the Ku band data uplink -- Program updates may be made through out the orbital phase. Continuous acceleration data will be transmitted to earth using the Ku-bank data ground link and only occasional data will be recorded on the VFR experiment recorder.

Presently Spacelab III is tentatively scheduled for an eight day orbit duration with various VFR periodic spin cycles, series of cycles and continuous artificial gravity simulation for extended periods. At the conclusion of the orbital mission, the Spacelab will be deactivated. However, before deactivation occurs, the last spin cycle and data acquisition occurs followed by specimen transfer. Three frog specimen canister will be demated and removed from the centrifuge and transferred to the mid-deck location. The flight life support system is then deactivated in the Spacelab and transferred to the designated mid-deck locker area, activated and connection completed to the three previously transferred specimens. The remaining three canisters will then be transferred from Spacelab to the mid-deck location. Data will not be acquired or recorded in the mid-deck location. Orbiter thermal conditioning will be accomplished in the six hours prior to re-entry. Upon completion of thermal conditioning the orbiter will re-enter and land at the KSC landing site.

As the orbiter slows and stops, after landing, the VFR transport van will approach the mid-deck access hatch along with the access vehicle. Certain access preparations are required prior to crew exchange. The ground crew will enter the mid-deck area approximately 40 minutes after touchdown and immediately commence specimen canister removal. Each will be individually transported to the hatch where another ground crew member will receive them and carry them to the van. As each canister is received it will be mounted to the transport unit and connected to the temperature stabilized life support system and the data system for immediate data recording of biological, engineering and housekeeping data.

The specimens will then be transported to the MSOB, off loaded and initial quick look data recorded reduced and analyzed as required.

Following these tests the specimens and equipment will be configured and prepared for the return trip to the PI's laboratory using the ten frog GSE. Final testing, data analysis etc., will be performed at the PI's laboratory.

VFR Experiment Personnel Requirements

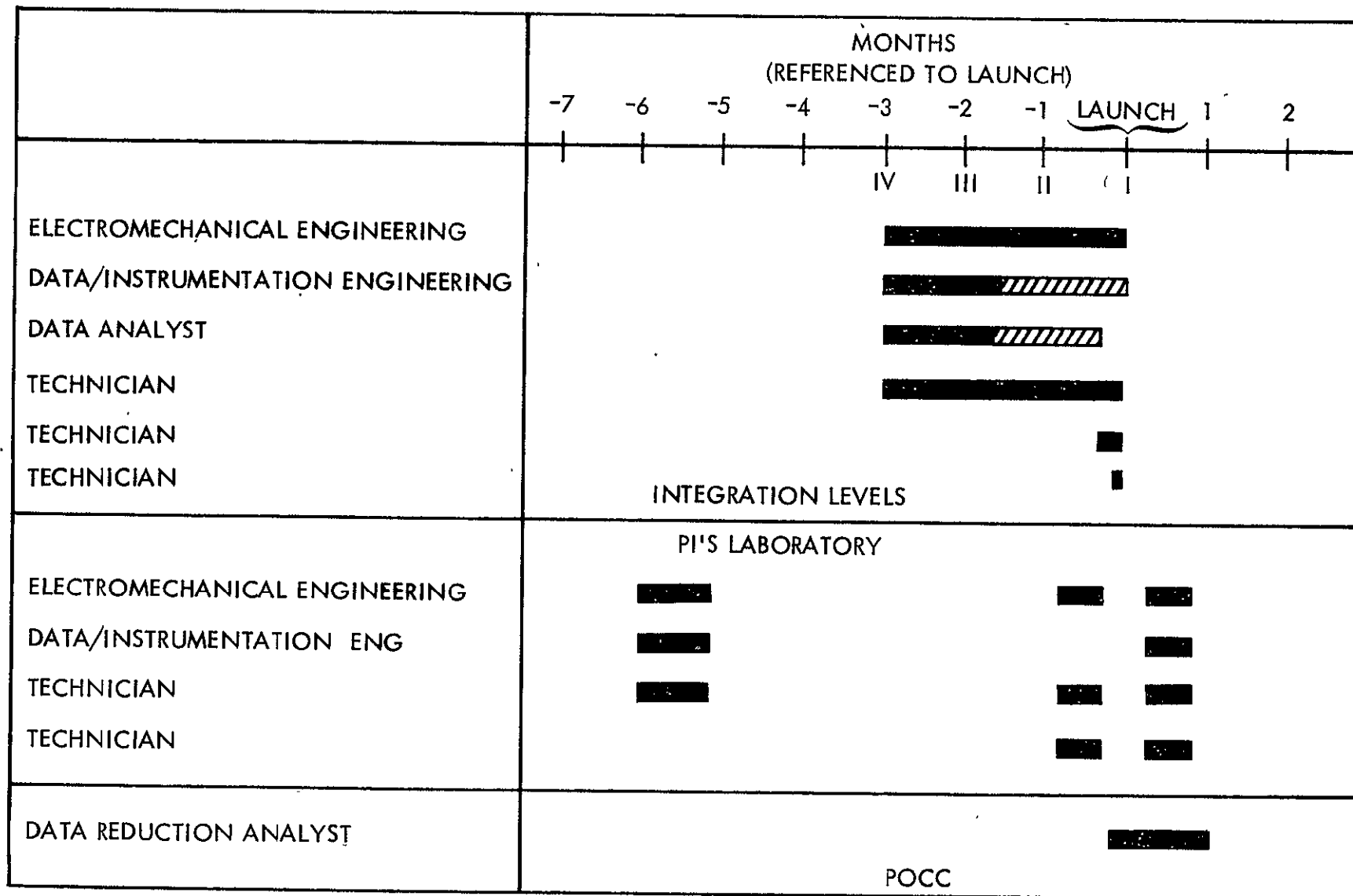
Fig. 107 presents personnel requirements for experiment support at the PI's laboratory during level IV, III, II and I integration and post flight operations.

The following paragraphs describe the support activities relative to personnel requirements.

The qual unit and the ten frog GSE equipment will be shipped to the PI laboratory approximately 5 to 6 months before the scheduled launch. This will provide centrifuge performance capability duplicating that of the flight unit and will be supported by electronic control and displays. Additionally the GSE equipment will provide life support, data reduction and displays for ten additional frog specimens installed in canisters.

Two engineers and one technician can support the setup and operational start-up at the PI's laboratory. They would remain for two to three weeks for their effort and additional on-call assistance could be made available, if required, up to the time of the transfer of equipment and specimens to KSC.

During level IV build-up, installation and testing, personnel required to support the hardware have been identified as three engineers and one technician. As integration progresses in levels III and II, it is anticipated that the continued level of engineering personnel support will not be necessary and will be reduced accordingly as shown.



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Figure 107 VFR Experiment Personnel Requirements

Approximately two weeks prior to the scheduled launch, preparation could begin for transport of the specimens from the PI's laboratory to KSC for the final preflight specimens testing and flight preparations.

Personnel to support this effort is one engineer and two technicians.

At KSC final testing will be conducted and preparation for flight accomplished. Support for this effort including specimen loading into the Spacelab, will be provided by one engineer and three technicians.

After the flight, it is anticipated that the hardware will return to the PI's laboratory for completion of tests. One engineer and two technicians will support the hardware and specimen return to the PI's laboratory.

During prelaunch, orbit operation and approximately two weeks after, a data reduction analysis may be required to assist the PI.

STS Onboard Equipment Requirements

The Orbiter and Spacelab equipment required to support the orbital VFR experiment is presented by Table 21. The orbiter supporting equipment is primarily in the area of up and down link data communication, power and locker space required during thermal conditioning and re-entry. The Spacelab equipment support is principally for data, experiment computer capability, and power.

TABLE 21
STS ON BOARD EQUIPMENT

ORBITER

Ku-Band Down Link
Ku-Band Signal Processor
General Purpose Computer
MUX/DEMUX
Network Signal Processor
Electrical Power Distribution System (Mid-Deck)

Table 21 STS ON BOARD EQUIPMENT (continued)

SPACE LAB

Experiment Computer
Mass Memory Unit
Experiment I/O unit
Experiment Remote Acquisition Unit
Data Display System
High Rate Multiplexer
High Data Rate Recorder
Electrical Power Distribution System (Essential Power)

C-4

EXPERIMENT EQUIPMENT COST ESTIMATE

A baseline schedule and estimate of the manhours and cost for the detailed design, fabrication, assembly, test, integration, and flight operation for the VFR Program have been prepared based on the following data:

- Preliminary Design
- Work Breakdown Structure (WBS) for Phases C & D
- Program Requirements List
- Preliminary Phases C & D Schedules
- Statements of Work (SOW)
- Document Requirements List

The reliability, quality assurance and safety programs designed specifically for Phases C and D are described in Appendix A of Program Plan.*

Cost Elements

LMSC's approach to estimating the cost for the VFR Program (Phases C and D) is by identifying the scope of work in terms of Work Breakdown Structure (WBS) and the Statement of Work, the span of work by a master schedule consistent with the WBS and NASA guidelines, the end products by Program Management Networks, and the material required by a Program Requirements List (PRL).

Work Breakdown Structure (WBS)

The WBS, Figure 108, was prepared for this cost estimate and permits cost identification to the third-level for all elements and to the fourth-level for special requirements, e.g. development test costs. Phases C & D costs can be easily separated and Reliability/Quality Assurance and Safety costs are identified separately.

The method used to develop costs was based on analyzing the Statement of Work and identifying subtasks under each third-level WBS. For example under WBS

*Prepared as part of the Final Program Plan, LMSC-D566954 dated 17 May 1978.

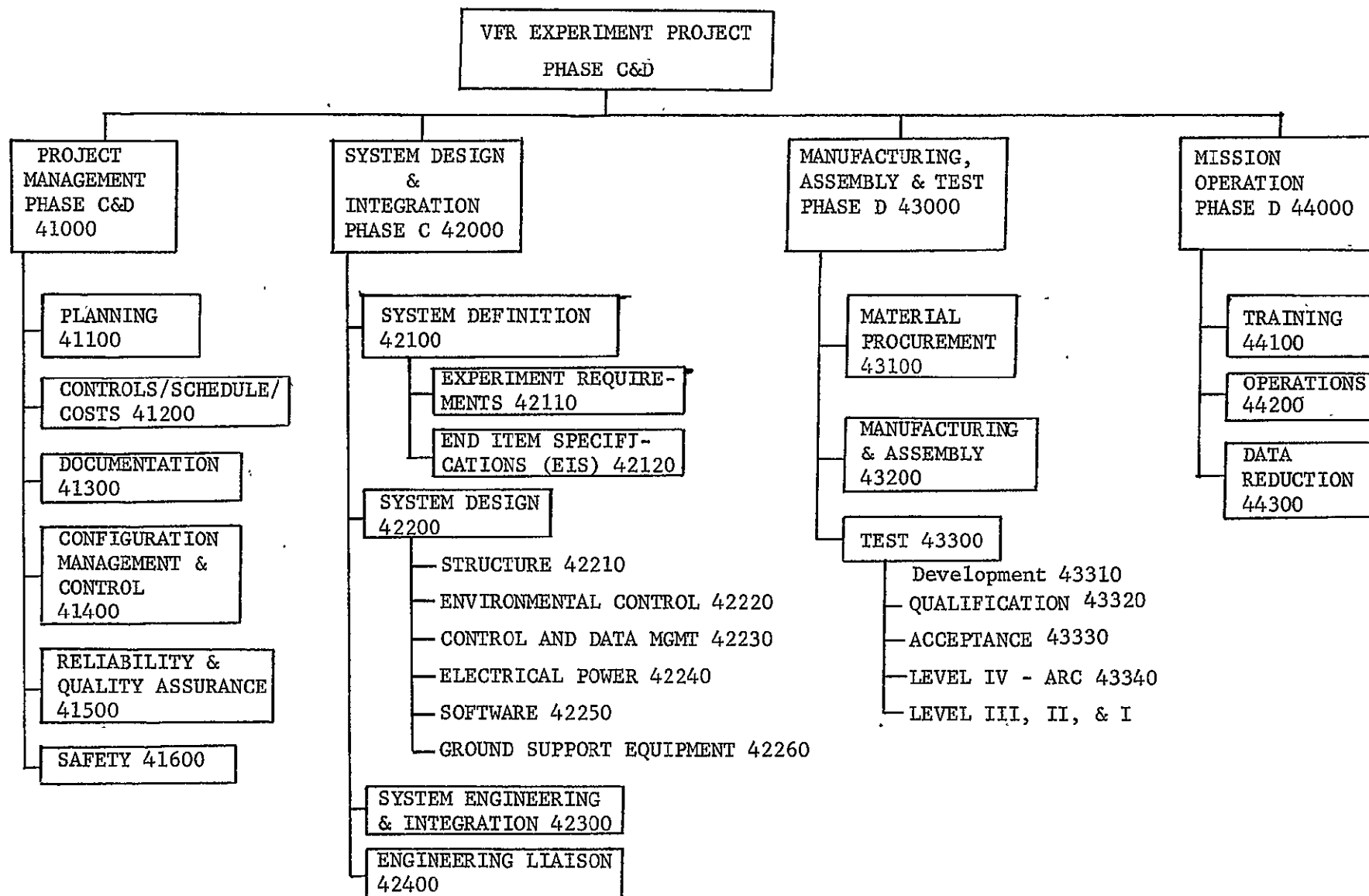


Figure 108 VFR Work Breakdown Structure (WBS)

42100 -- Definition, the task WBS 42110 -- Requirements was further broken-down into subtasks of preparing Preliminary and Final Requirements and providing typing and technical publication support. Cost Input Worksheets were then used to timespan the hours estimated for each task. Experienced engineers developed cost estimates in their areas of design using schematic block diagrams and past experience. Manufacturing developed cost estimates based on the design layouts, similar projects and as a function of the design effort.

Assumptions used in the cost estimate were:

- Spacelab 3 Flight Data -- June 9, 1981, 15:44 EST*
- One Development Unit
- One Qualification Unit
- Flight/Backup Unit -- 1 ea.
- Normal manlevels for Reliability/Quality Assurance
- Normal indirect support available, e.g. Manager/Planning, Subcontract, Procurement, and Finance
- Documentation preparation and production charged to the doing function, e.g. System Design and Integration (WBS 42000) responsible for ERD and EIS's
- Normal burden cost added to basic material estimate
- Normal Ground Support Equipment (GSE) to be developed
- Flight and Ground Software to be developed
- Interface with Automatic Checkout Equipment to be developed
- Installation and Checkout Fit and Function at NASA-ARC
- Level IV Integration support provided at NASA-JSC
- Level III through I Integration are prime responsibility of NASA-KSC, however, LMSC would provide support personnel to monitor and observe payload activity and be present to assist in any problems
- Training to be provided at Acceptance Test and at Level IV Integration
- Operation to include data reduction and refurbishment of the flight hardware after mission is completed.

*Spacelab Mission Three -- Additional Payload Candidate Assessment, MSFC, Mar. 27, 1978 Org. EL34.

Schedule

A schedule is shown in Figure 109 which depicts the Phase C Definition being initiated Oct. 1, 1978 and being completed in one year. Phase D begins with the release of engineering drawings (Oct. 1, 1979) and is completed with the refurbishment of the flight unit by September 1, 1981. Total program period (Oct. 1, 1978 to Aug. 31, 1981) is 35 months. This schedule is consistent with and based on the Spacelab Payload Mission 3 Master Schedule Part 1.* Level IV Integration is to be initiated on December 15 and is concluded in four months.

Major milestones shown are PDR 3-months after go-ahead, followed by CDR 9-months after go-ahead. Early drawing release at this point will allow the fabrication of the development unit to proceed with its manufacture and test scheduled for completion 14-months after go-ahead. Manufacture and test of the qualification unit is scheduled for completion 22-months after go-ahead. Flight unit acceptance test will be completed 27-months after go-ahead. Level IV through I Integration then commencing. As shown on the schedule, launch occurs on June 9, 1981 and subsequent events are post-launch data reduction and refurbishment concluded 35-months after go-ahead.

Program Management Networks (PMN)

PMN's were developed to establish interrelationships and constraints among the tasks to be accomplished, inputs required from other sources, time-phasing for these interrelated inputs, and tracking of WBS accomplishment. PMNs assure the start-up and completion of a task on schedule or provides an early alert to problem areas, so contingency actions can be taken. Their usefulness in preparing cost inputs is that they give a clearer visibility and degree of importance to the subtasks which often is not conveyed by just the WBS or the SOW. PMNs used for cost generation are shown in figures 110 through 112. As noted on the respective figures, each PMN addresses a major WBS item.

*Spacelab Payload Mission 3 Master Schedule Part 1, Issue Date Dec. 1977, Status as of March 1978 - Control Room Spacelab Payload Office.

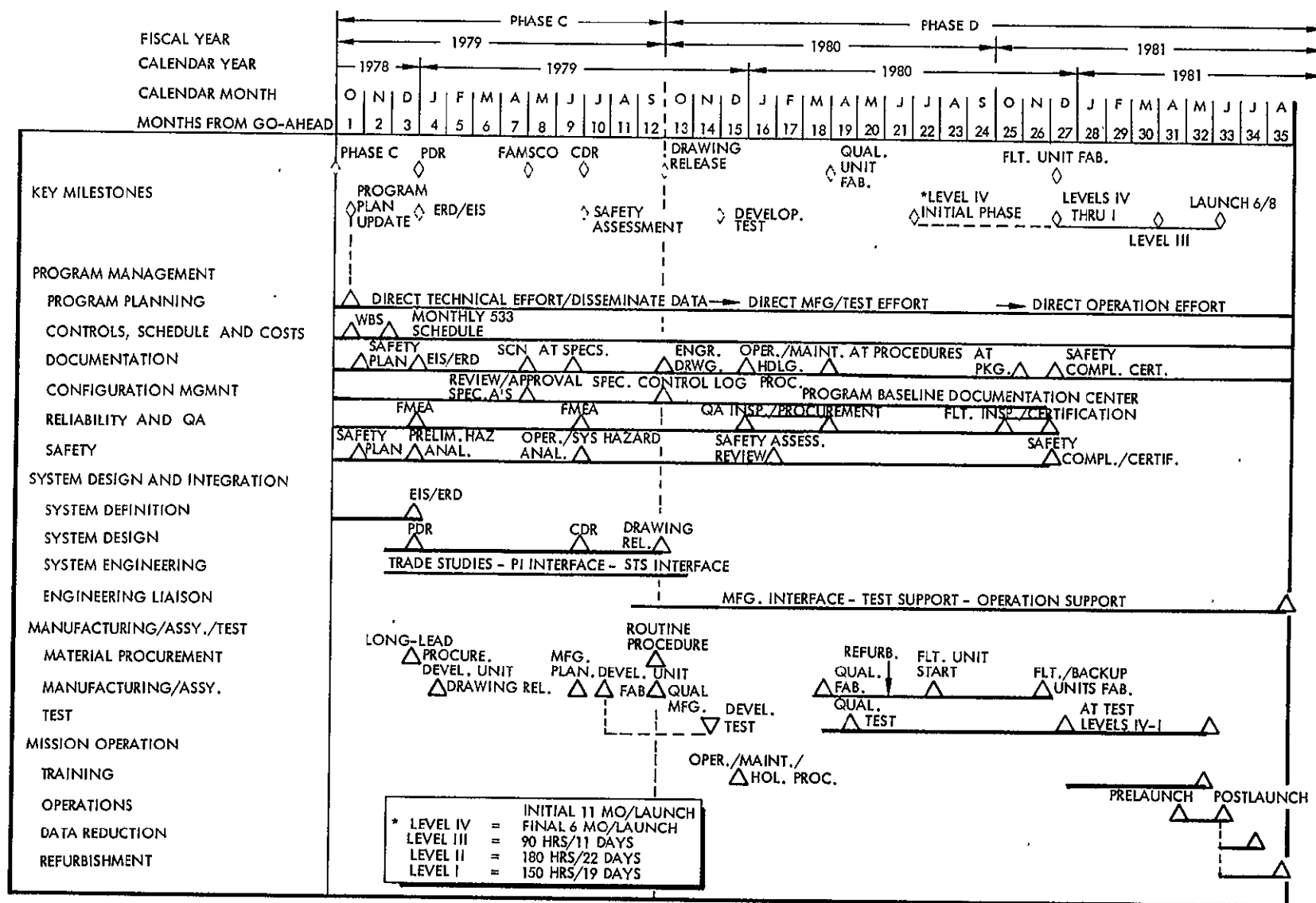


Figure 109 VFR Experiment Schedule

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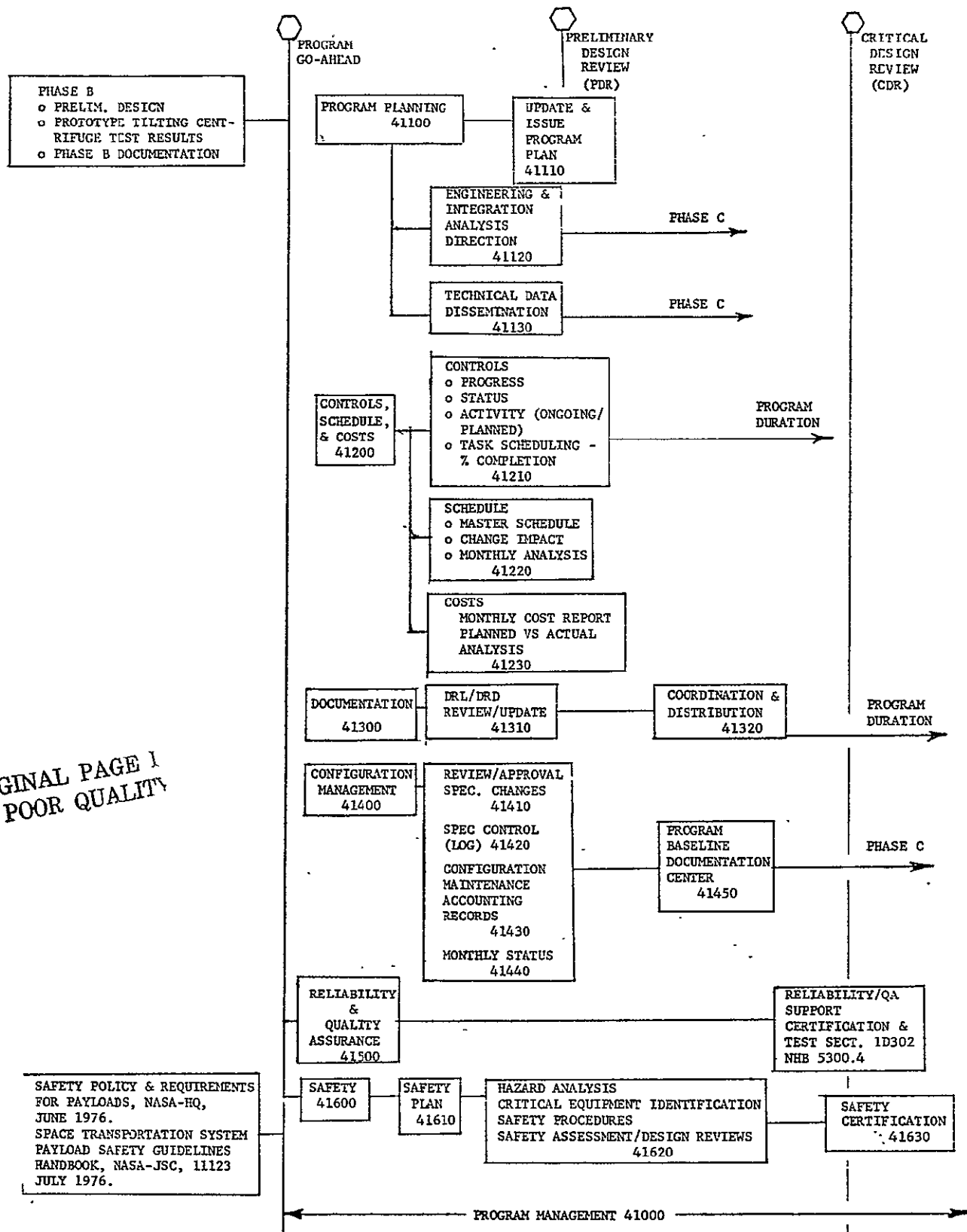


Figure 110 Program Management Network (PMC) - Program Management

272

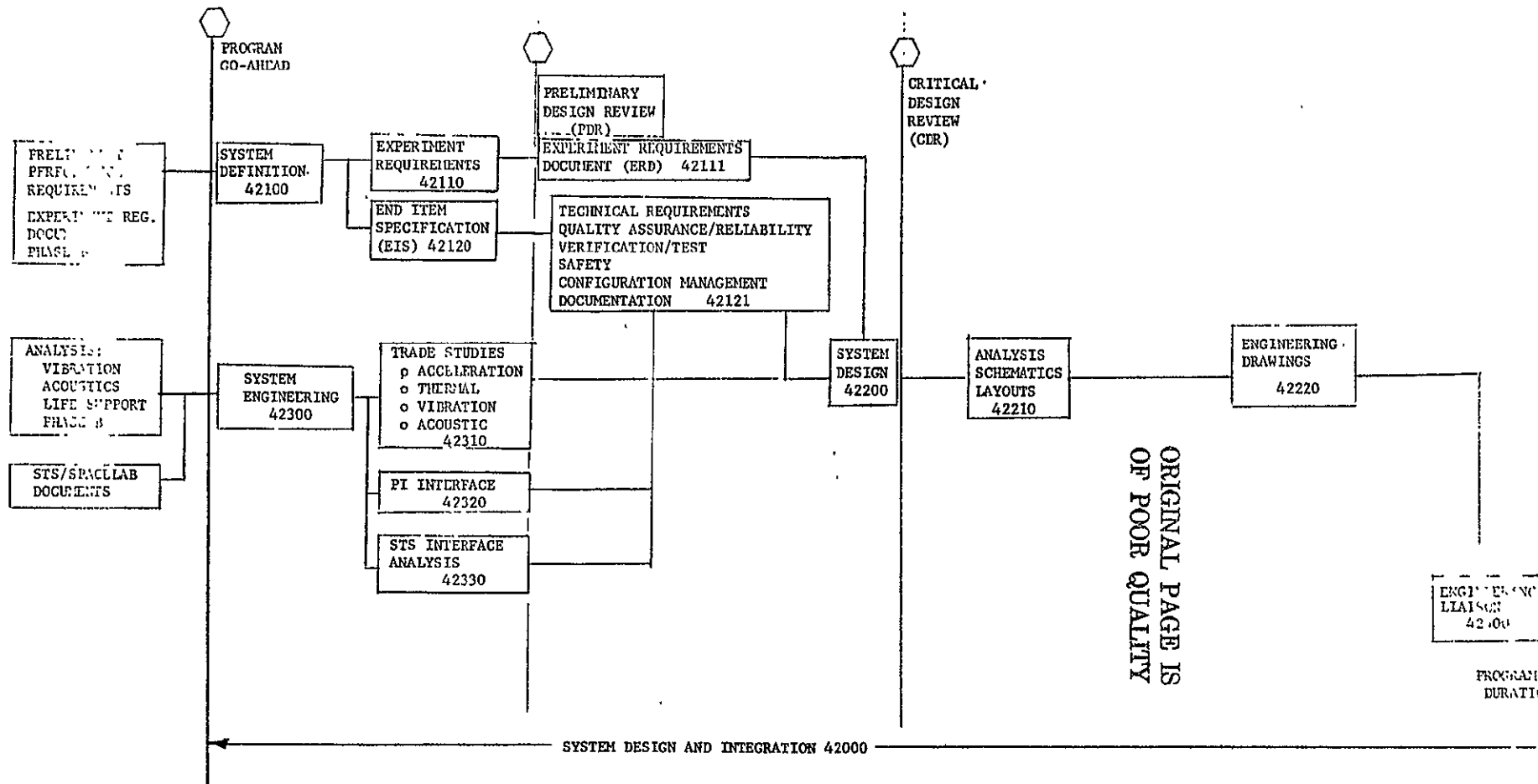


Figure 110 Program Management Network (PMN) (continued)

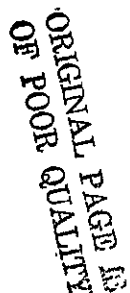


Figure 111 Program Management Network - Manufacturing, Assembly and Test

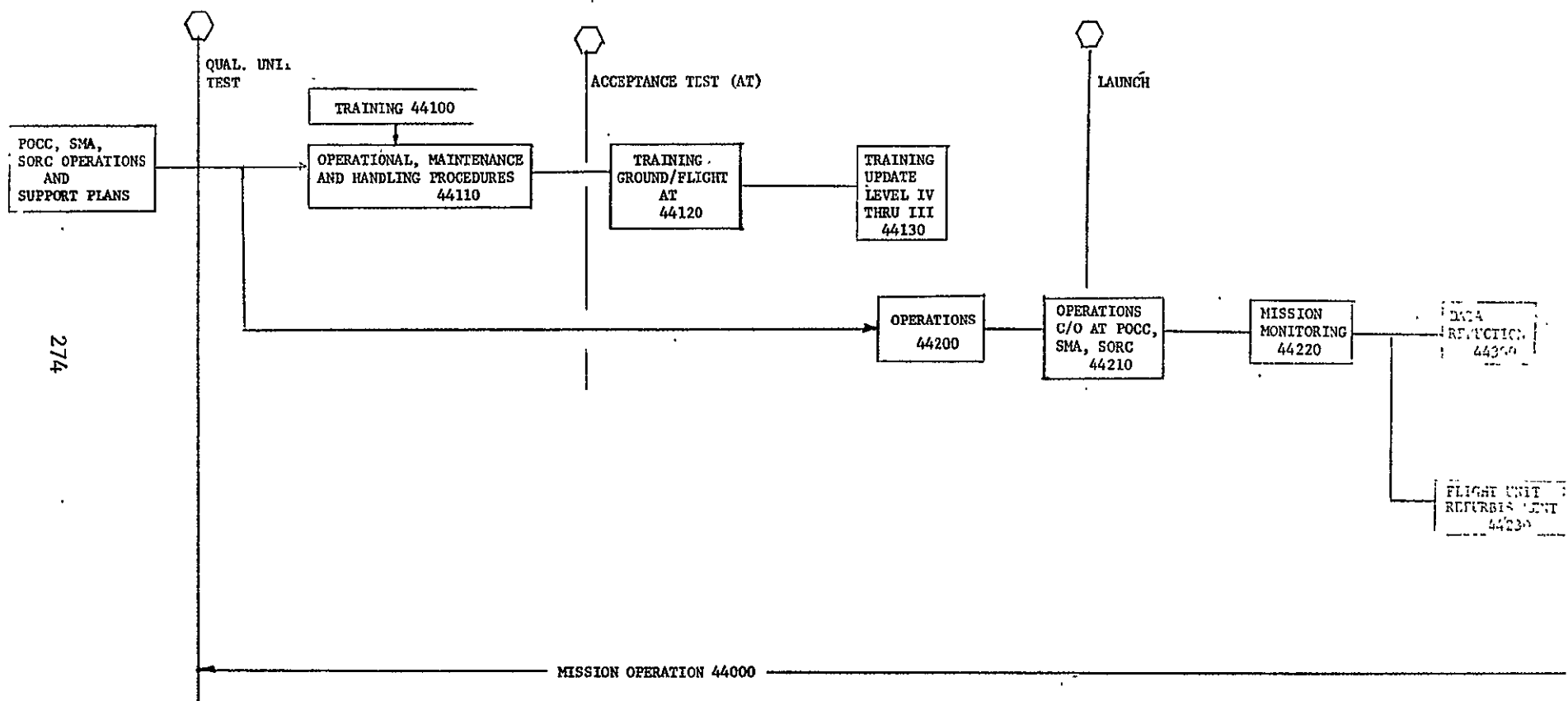


Figure 112 Program Management Network - Mission Operation

Program Requirements List

The Program Requirements List (PRL) - Table 22 has been organized to be consistent with the WBS and provides a source for collection of design and material costs. Other data contained within the PRL are: model numbers, status of design and hardware (existing - E, new - N, or modify - M), category (development, qualification, flight and spare) and quantity required. Lead-time is also noted. Long-lead items have been identified e.g., centrifuge drive motor and rotary joints/slip rings - 6 months.

Cost Summary

Costs are presented under separate cover.

Potential Cost Reductions

The classification of the VFR Experiment Equipment as "Class B, Nominal Confidence - Instruments and their dedicated spacecraft systems, which are cost constrained to the extent that acceptance of failure risk is considered acceptable, when it is cost effective*", offers potential cost reductions.

*Policy on NASA Payloads - Memo from AA/Associate Administration
June 20, 1977.

PROGRAM REQUIREMENTS LIST

PROGRAM OFFICE APPROVAL
ORGN. NO.: 52-04 NAME: Biotechnology

ITEM NO.	NOMENCLATURE	DRAWING NUMBER (or similar to)	RECOMMENDATIONS			QUANTITY PER CONTRACT						AVERAGE TOTAL UNIT OR MOD. COST	LEAD TIME (IN MOS.)	REMARKS
			MAKE OR BUY	STATUS		CATEGORY								
				DESIGN	HDVE.		D	Q	F	S	TOT			
1	Tilting Centrifuge Base Mount		M		N		1	1	1	1	4			AR - As Required
	Main Centrifuge Drive Assy.													
	Drive Motor		B		E		1	1	1	1	4			
	Optic Encoder		B		E		1	1	1	1	4			
	Bearings		B		E		AR	AR	AR	AR	AR			
	Slip Rings		B		M		1	1	1	1	4			
	Rotary Fluid Joints		B		E		12	12	12	12	48			
	Mid Base Mount		M		N		1	1	1	1	4			
	Centrifuge Body Mounted Flanges		M		N		4	4	4	4	16			
	Centrifuge Body		M		N		1	1	1	1	4			
	Canister Support Structure		M		N		4	4	4	4	16			
	Canisters		M		N		4	4	4	4	16			
	Tilt Drive Motor Assy		B		E		4	4	4	4	16			
2	Life Support													Inner/Outer
276	O ₂ Plus Bottle & Shutoff Valve		B				1	1	1	1	4			
	O ₂ Regulator		B				1	1	1	1	4			
	Air Pump		B				1	1	1	1	4			
	Lung		B				1	1	1	1	4			
	Filter Assy.		M				1	1	1	1	4			
	Accumulator		M				1	1	1	1	4			
	Circulation Pump		B				1	1	1	1	4			
	Relief Valves		B				2	2	2	2	8			
	Quick Disconnects		B				6	6	6	6	24			
	Misc. Lines, Fittings, Wiring		B				AR	AR	AR	AR	AR			
	Wash Pump		B				1	1	1	1	4			
	Baralyne Canister		M				1	1	1	1	4			
3	Control Canister													CO ₂ Removal
	Housing - Canister						2	2	2	2	4			
	Fitting						AR	AR	AR	AR	AR			For Control Specimens (2)
4	Data System													
	Data Instrumentation													
	pO ₂		B		E		6	6	6	6	24			
	Temperature - Canisters		B		E		6	6	6	6	24			
	Acceleration - Centr. Base		B		E		3	3	3	3	12			

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PROGRAM
REQUIREMENTS LIST

977

ITEM NO.	NOMENCLATURE	DRAWING NUMBER (or similar to)	RECOMMENDATIONS			QUANTITY PER CONTRACT					AVERAGE TOTAL UNIT OR MOD. COST	LEAD TIME (IN MOS.)	REMARKS
			MAKE OR BUY	STATUS		CATEGORY							
				DESIGN	HCVE.	D	Q	F	S	TOT			
4	Data Instrumentation (continued)												
	Temperature - Life Support		B		E	1	1	1	1	4			Water Inlet
	pH - Life Support		B		E	1	1	1	1	4			Water Inlet
	pCO ₂		B		E	1	1	1	1	4			
	Turbidity		B		E	1	1	1	1	4			Water Inlet
	O ₂ Tank Pressure		B		E	1	1	1	1	4			
	P - Life Support Pump		B		E	1	1	1	1	4			
	P - Bleed Pump		B		E	1	1	1	1	4			
	P - Wash Pump		B		E	1	1	1	1	4			
	P - Gas Pump		B		E	1	1	1	1	4			
	P - Coarse Filter		B		E	1	1	1	1	4			
	P - Fine Filter		B		E	1	1	1	1	4			
	P - Thermo Elect. Blower		B		E	1	1	1	1	4			
	TE Unit - Voltage		B		E	1	1	1	1	4			
	TE Unit - Current		B		E	1	1	1	1	4			
	TE Unit - Temp.		B		E	1	1	1	1	4			Water Inlet
	Controller Position		B		E	4	4	4	4	16			Centrifuge Canisters
	Controller Rate		B		E	1	1	1	1	4			Centrifuge
	Signal Cond - Current		B		E	1	1	1	1	4			
	Signal Cond - Voltage		B		E	1	1	1	1	4			
	TIM - On/Off Command		B		E	1	1	1	1	4			
	LSS - On/Off Command		B		E	1	1	1	1	4			
	Centrifuge - On/Off Command		B		E	2	2	2	2	8			
	T/R - On/Off Command		B		E	1	1	1	1	4			
	EKG Gain - Hi Lo		B		E	6	6	6	6	24			
	PCM MUX - Hi/Lo/Med		B		E	3	3	3	3	12			
	Sig. Cond. - Accel Cal/Mon.					7	7	7	7	28			
	TRK/SEL - 1/2 thru 13/14					7	7	7	7	28			
	SPD/SEL -					4	4	4	4	16			
	Mode - Rec/Pbk					1	1	1	1	4			
	Mode - Fwd/Rev.					1	1	1	1	4			
	Mode - Run/Stop					1	1	1	1	4			
	Mode - Erase					1	1	1	1	4			
	Controller - PRN Mode/Sel					5	5	5	5	20			
	HRM - FMT CH/NC					1	1	1	1	4			

PROGRAM
REQUIREMENTS LIST

ITEM NO.	NOMENCLATURE	DRAWING NUMBER (or similar to)	RECOMMENDATIONS			QUANTITY PER CONTRACT						AVERAGE TOTAL UNIT OR MOD. COST	LEAD TIME (IN HRS.)	REMARKS
			MAKE OR BUY	STATUS		CATEGORY								
				DESIGN	DEVELOP.	D	Q	F	S	TOT				
4	Data System (continued)													
	Analog/Digital Tape Recorder					1	1	1	1	4				14 Track
	VCO Assy - Expr.					1	1	1	1	4				
	VCO Assy - Control					1	1	1	1	4				
	PCM MUX					1	1	1	1	4				
	PCM MUX Control					1	1	1	1	4				Bit Stream
	Selector Switch					1	1	1	1	4				
5	Electrical/Electronics													
	Cables/Connectors					AR	AR	AR	AR	AR				
	Power Supplies/Battery					AR	AR	AR	AR	AR				
6	Communications/Command/Control													
	Microprocessor					1	1	1	1	4				
	Memory					1	1	1	1	4				
	MPLX - Service Req.					1	1	1	1	4				
	MPLX - Interrupt					1	1	1	1	4				
	A/D Converter					1	1	1	1	4				
	Device Select Logic/Serial Interface					2	2	2	2	8				8 Bit.
	Servos					9	9	9	9	36				
7	Thermal Control													
	Thermo Electric (TE) Module		B	M		1	1	1	1	4				
	TE Fan		B		E	1	1	1	1	4				
	TE Controller		M	M		1	1	1	1	4				
8	Bioinstrumentation													
	Microelectrodes - Otolith		GFE			12	12	12	12	48				PI Implant
	EKG		GFE			6	6	6	6	24				PI Implant
	Accelerometers		B	M		6	6	6	6	24				10 ⁻³ Frog Head-Mounted/PI
	Accelerometers		B	M		6	6	6	6	24				10 ⁻³ Canister Mounted
9	Ground and Flight Support Equip.													
	(GSE & FSE)													
	Data Ground Station		M	N										
	Control Unit		M	N										
	Simulator		M	N										
	Resupply Cart		M	N										

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LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

PPL. NO.

TITLE

Table 22

VFR EXPERIMENT EQUIPMENT

PROGRAM OFFICE APPROVAL

ORGN. NO.: 52-04

NAME: Biotechnology

LEGEND

STATUS

CATEGORY

DATE

5 May 1978

REVISION

PAGE

OF

E = EXISTING

D = DEV.

Q = QUAL.

N = NEW

R = REL.

M = MODIFY

F = FLIGHT

S = SPARES

PROGRAM
REQUIREMENTS LIST

ITEM NO.	NOMENCLATURE	DRAWING NUMBER (or similar to)	RECOMMENDATIONS			QUANTITY PER CONTRACT						AVERAGE TOTAL UNIT OR MOD. COST	LEAD TIME (IN MOS.)	REMARKS
			MAKE OR BUY	STATUS		CATEGORY								
				DESIGN	HC/E.		D	Q	F	S	TOT			
9	Ground and Flight Support Equip. Core Spacelab Subsystems	(continued)	GFE GFE											

279

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Cost reduction is achieved by a minimum level of assurance effort involving failure identification, quality assurance elements, test/engineering models, acceptance testing, electrical, electronic and electromechanical (EEE), parts and mechanical control. Accompanying this effort is a substantial reduction in deliverable documentation and drawing level sufficiently detailed to effect manufacturing of the end item. Table 23 summarizes the elements involved in cost reduction and compares typical quality assurance and testing criteria imposed on a contract against reduced criteria associated with the Class B categorization.

Failure identification and corrective action functions, such as Failure Mode and Effects Analysis and single failure points summary, can consume extensive project resources. A nominal level of effort on the VFR project would identify potential failures as required to support safety analysis.

Limiting QA participation to critical items and final system assembly will reduce manpower levels.

The objectives that must be considered to provide an appropriate level of assurance for Class B instruments are to 1) preclude failure by appropriate over design, 2) accommodate retrieval/repair, and 3) accept risk of failure to achieve experiment/objectives.

Table 24 furnishes further classification as to the documentation effort that would occur under this low cost approach and compares typical documentation requirements imposed on a contract against reduced documentation associated with the Class B categorization.

The low cost approach to configuration management is contingent on minimizing the number of drawings, e.g., multiassembly drawings rather than monodetail. Other low cost techniques to be applied are:

Table 23 Assurance/Testing Criteria

Typical	Class B
Assurance/Testing Criteria	Assurance/Testing Criteria
Failure Identification and Corrective Action Functions - o Failure Mode & Effects Analysis and Single Failure Point Summary - o Effort to eliminate or compensate for potential failures identified. - o Failure reporting and analysis. - o Corrective actions on failures.	o Nominal level of effort to identify. Potential failures as required to support safety analysis and determine cost effective design option.
Typical Assurance Elements Contractually Imposed - o Process Certification & Monitoring - o Design Reviews - o Government Inspection - o Material Review Board - o Quality Survey Audits - o Traceability - o Internal Configuration Control - o Qualification and Verification Testing	Level of Effort None. (Contractor choice) - o No Government Inspection - o Internal Material Review Only - o No Qualification Survey Audits - o No Traceability - o Risk of Safe Failure Acceptable - o Payload can be reflowed
Test/Engineering Models	Use prototype concept in lieu of test model. No dedicated engineering models authorized.
Acceptance Testing	Perform thorough functional but no environmental acceptance testing.
Electronic Piece Part Selection	Commercial Allowed Note 1: High levels should be used if cost effective. Note 2: Not low grade.
Documentation Engineering Drawings MIL-STD-100 MIL-STD-5480 18 DRL items	<u>Deliverable Documents</u> - o Acceptable test report - o Configuration inventory - o Failures & corrective action log - o Safety report showing compliance with all safety requirements - o Dwgs MIL-D-1000 Form 3 - o Hardware Development Plan

Table 24 Documentation Requirements Comparison

<u>Typical Documentation Requirements Imposed On a Contract</u>	<u>Class B Experiment</u>
Engineering Dwg. MIL-D-100	Engineering Dwg. MIL-D-1000 Form 3
Review Minutes	Not Required
Acceptance Review Report	Acceptance Test Report
Technical Reports	Not Required
Certificate of Safety Compliance	Certificate of Safety Compliance
Nonconformance Reports All	Nonconformance Reports Significant Only
Acceptance Data Package	Reduced as indicated ⁽¹⁾
Problem Reporting (RA-378TA)	Informal Monthly Report
Equipment Logs	Retain In-House
Reliability Plan	Reduced in Scope and Complexity
Failure Mode and Effects Analysis Report	Not Required
Acceptance Test Spec/Procedures	Informal In-House
Test Reports - Development/Qual.	Test Reports - Development/Qual.
Operating, Maintenance & Handling Procedures	Informal Part of Acceptance Test Procedure

(1) Elimination of delivery of inspection records equipment logs and completed test procedure; summary of NCR's combined ATP/Operation/Maintenance/Handling/Storage Instructions.

- o No incorporation of Engineering Orders (EOs) unless necessary to read drawing.
- o Red-lining of drawing is permissible.
- o Follow MIL-D-1000 Form 3 format
- o Furnish only operational, maintenance service manuals as part of the acceptance test and procedure document.

Another potential cost reduction is associated with the Reliability classification of the VFR Program as to "Criticality Category". There are three classifications:

Criticality Category I. Contractors supplying Flight Hardware containing equipment whose failure could adversely affect flight crew safety shall comply with Chapter 3 of NHB 5300.4 (1D-1).

Criticality Category II. Contractors supplying Flight Hardware containing equipment whose failure could result in not achieving a primary mission objective but does not adversely affect crew safety shall comply with Chapter 3 of NHB 5300.4(1D-1), excluding Section 1D301-8.

Criticality Category III. Contractors supplying Flight Hardware of lower criticality than Categories I and II shall comply with Section 1D302 of NHB 5300.4(1D-1).

Experiment equipment is normally never classified as I, however, some equipment could be categorized as II, e.g. Space Telescope. However, the VFR experiment consists of flight hardware of lower criticality than Categories I & II and therefore should only comply with Section 1D302 of NHB 5300.4 (1D-1).

In summary, adoption of the two cost reductions; 1) Quality Assurance and Testing Reduced Criteria, and 2) Criticality Category III classification would account for a budgetary cost savings estimate for the VFR Program of approximately ten percent.